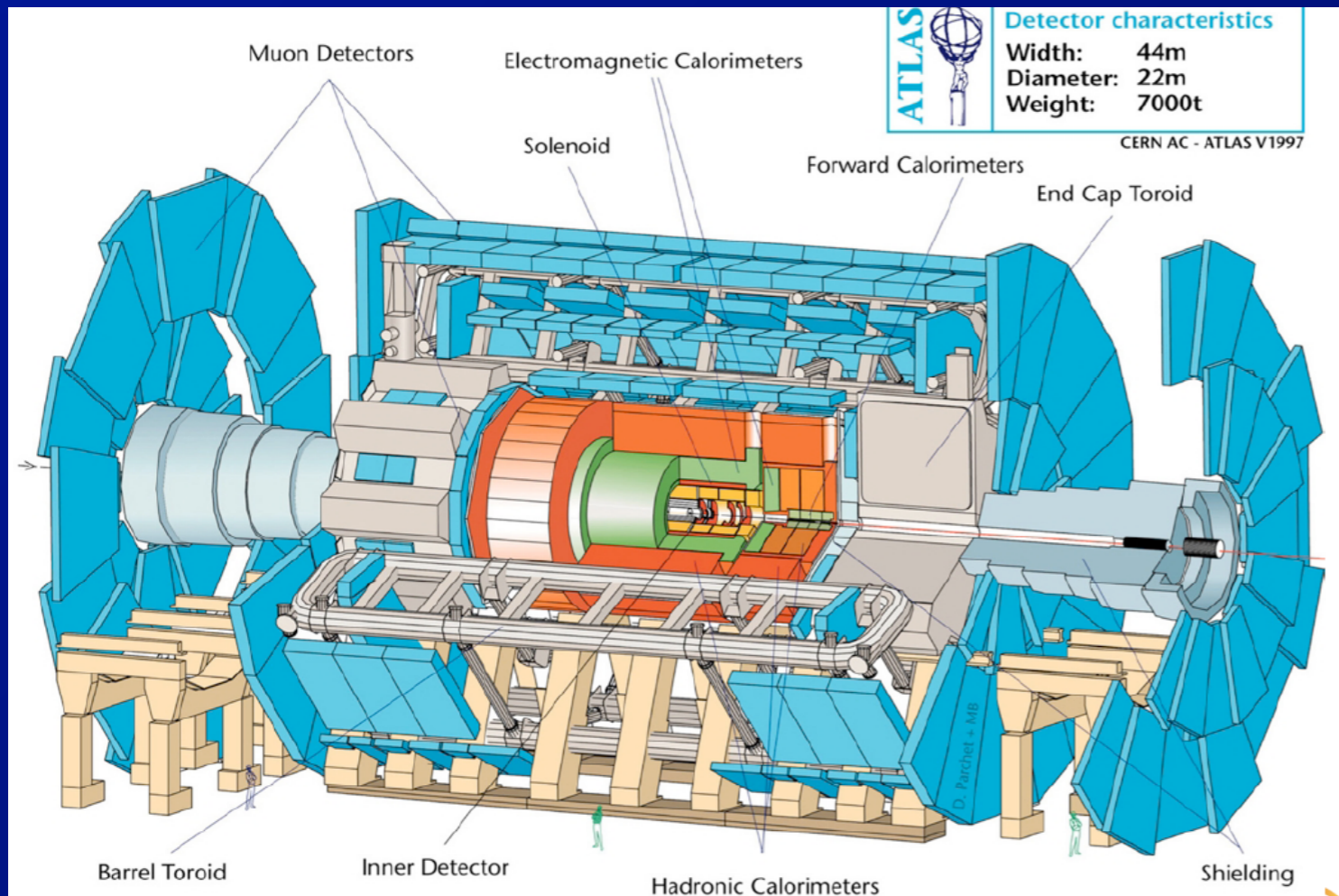


The ATLAS Heavy Ion Program

Brian A. Cole, Columbia University

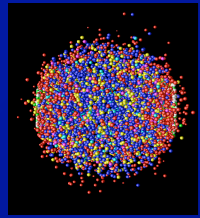
July 29, 2008



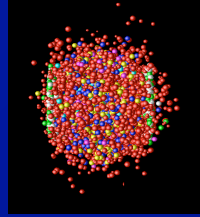
Outline

- **Open problems in HI physics: LHC input**
 - Initial particle production/saturation
 - Early collective expansion, sQGP
 - Jet quenching
- **ATLAS heavy ion program**
 - ATLAS detector
 - Global observables
 - Jets, jet fragmentation, multi-jet
 - Photons
 - Quarkonia
- **Summary**
 - ATLAS heavy ion physics program
 - Unique ATLAS contributions

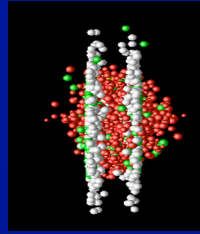
Ultra-relativistic A+A, Canonically



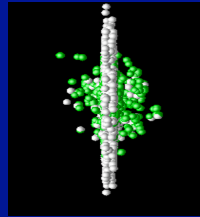
Recombination,
Hadronic cascade



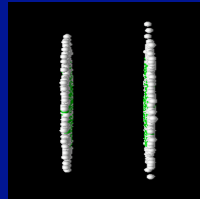
Hydro evolution



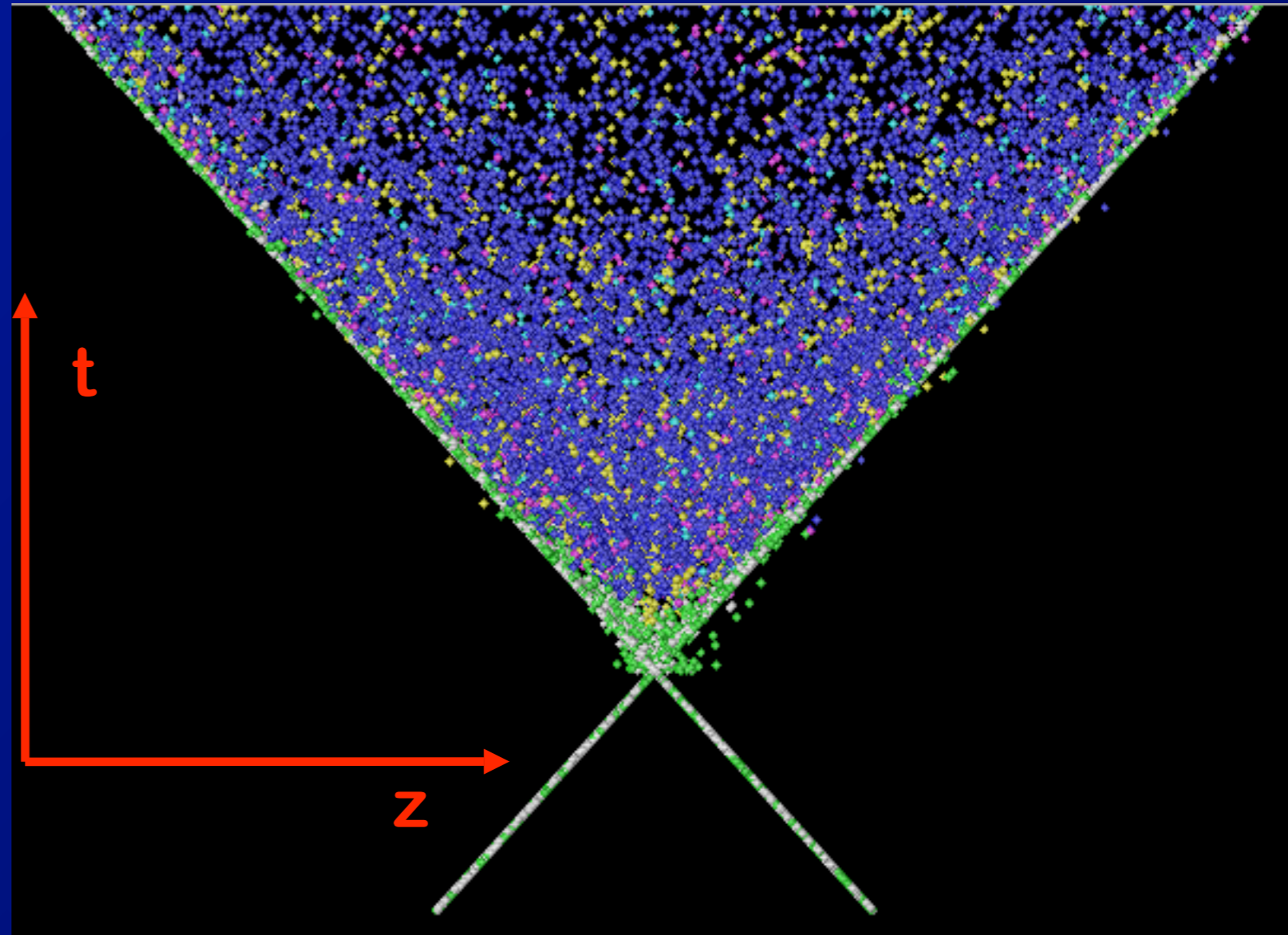
Fast thermalization



Hard processes,
CGC \rightarrow Glasma



Saturated nuclei

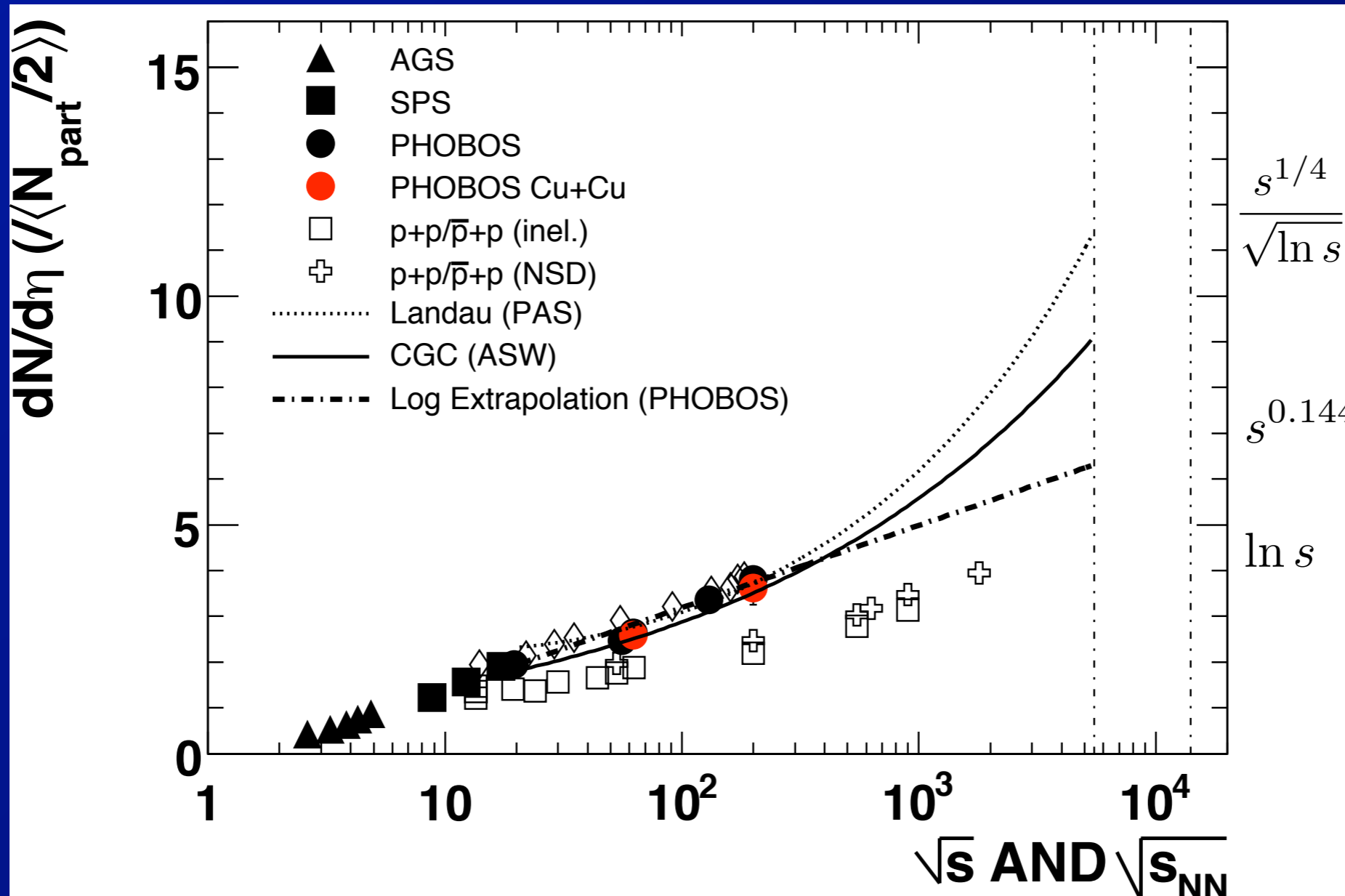


- How well do we understand each stage?

- How certain are we that the canonical interpretation is indeed the correct one?

\Rightarrow Need definitive tests!

Initial Conditions



'Landau'
(Carruthers 1974)

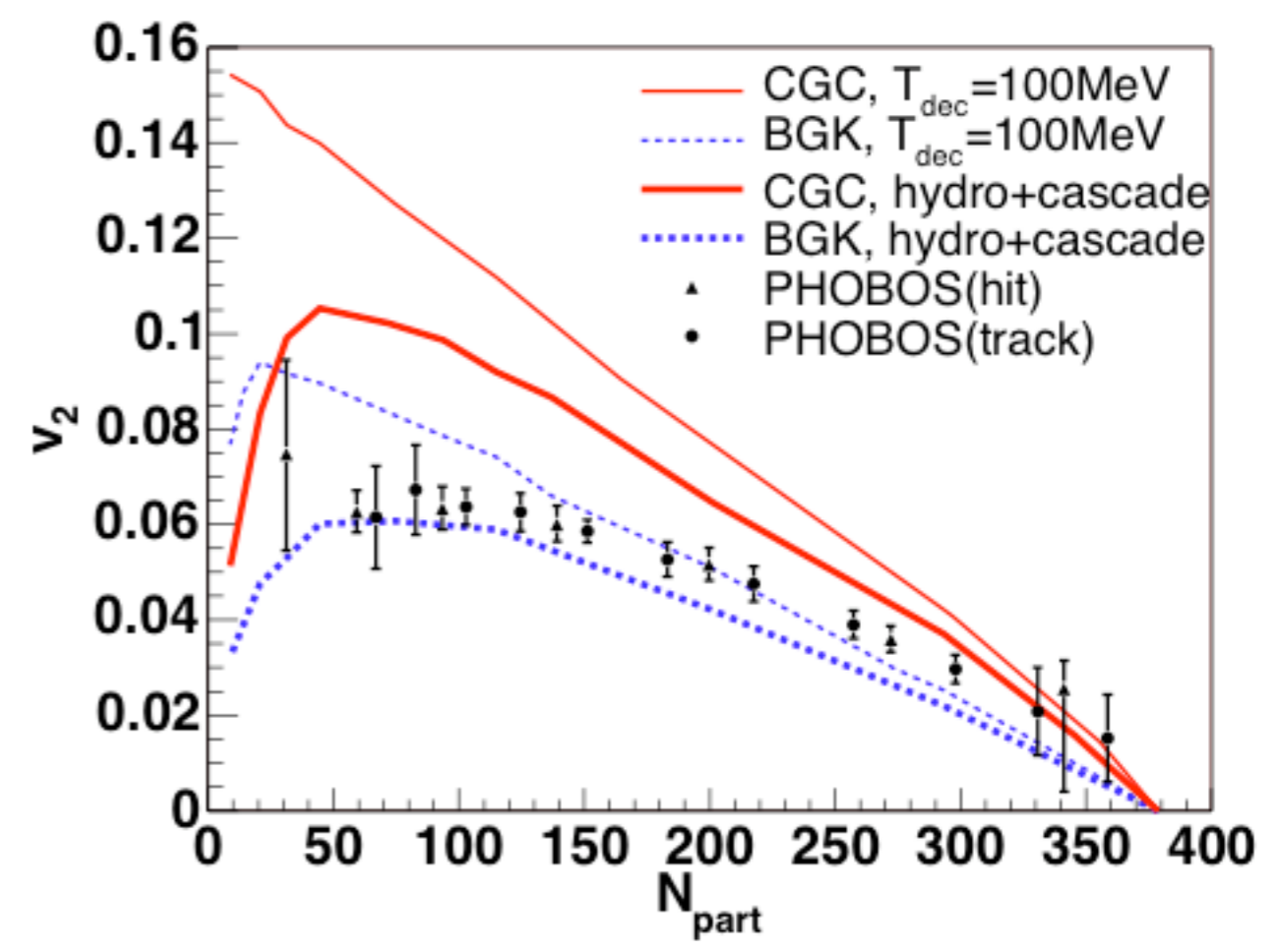
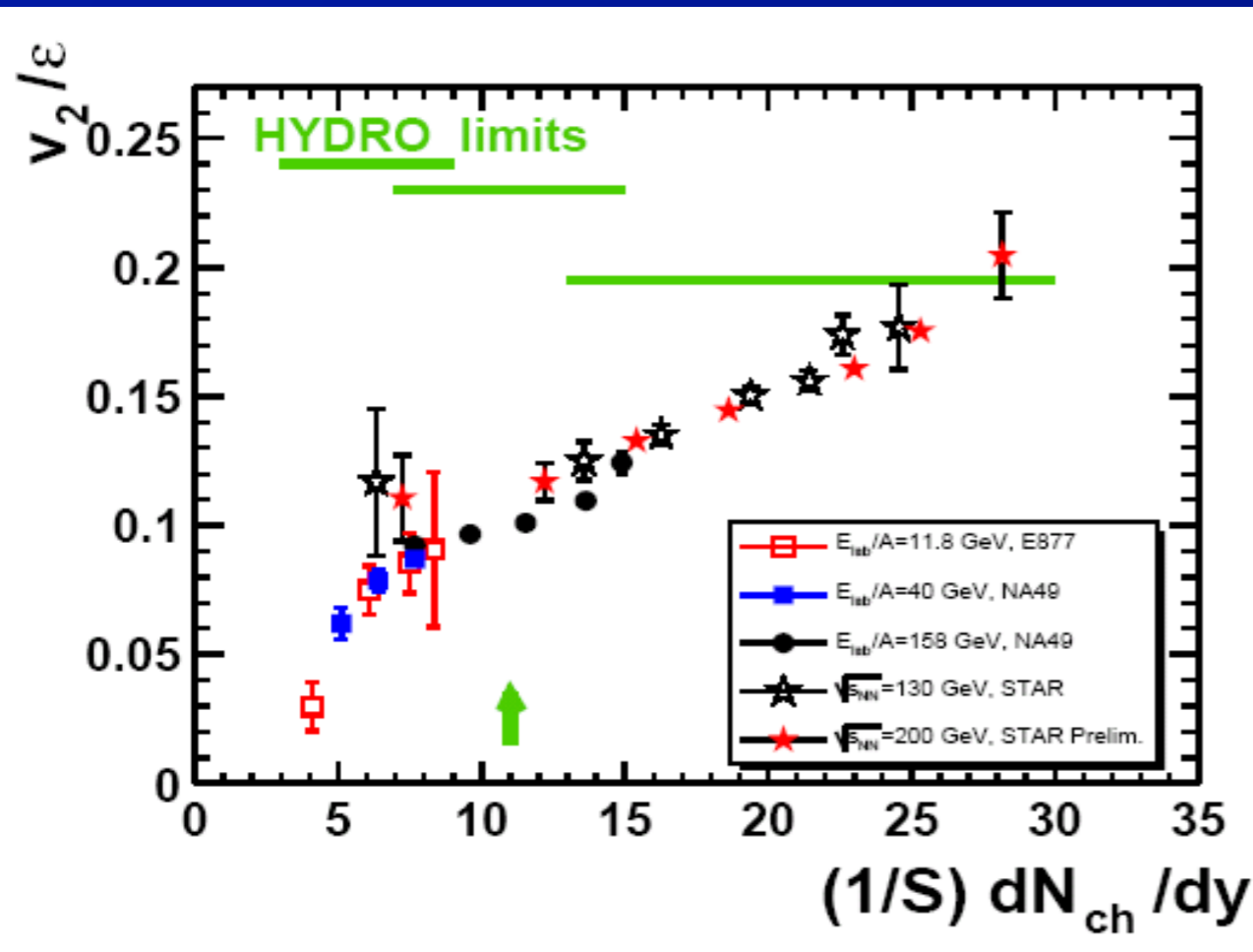
CGC:
arXiv:0707.0564

Busza/PHOBOS:
PRC 74 021901

• Is Glasma the correct paradigm?

- Measurement at higher \sqrt{s} will provide essential test
 \Rightarrow If we don't understand initial conditions, can we claim to understand flow, quenching, ... ?

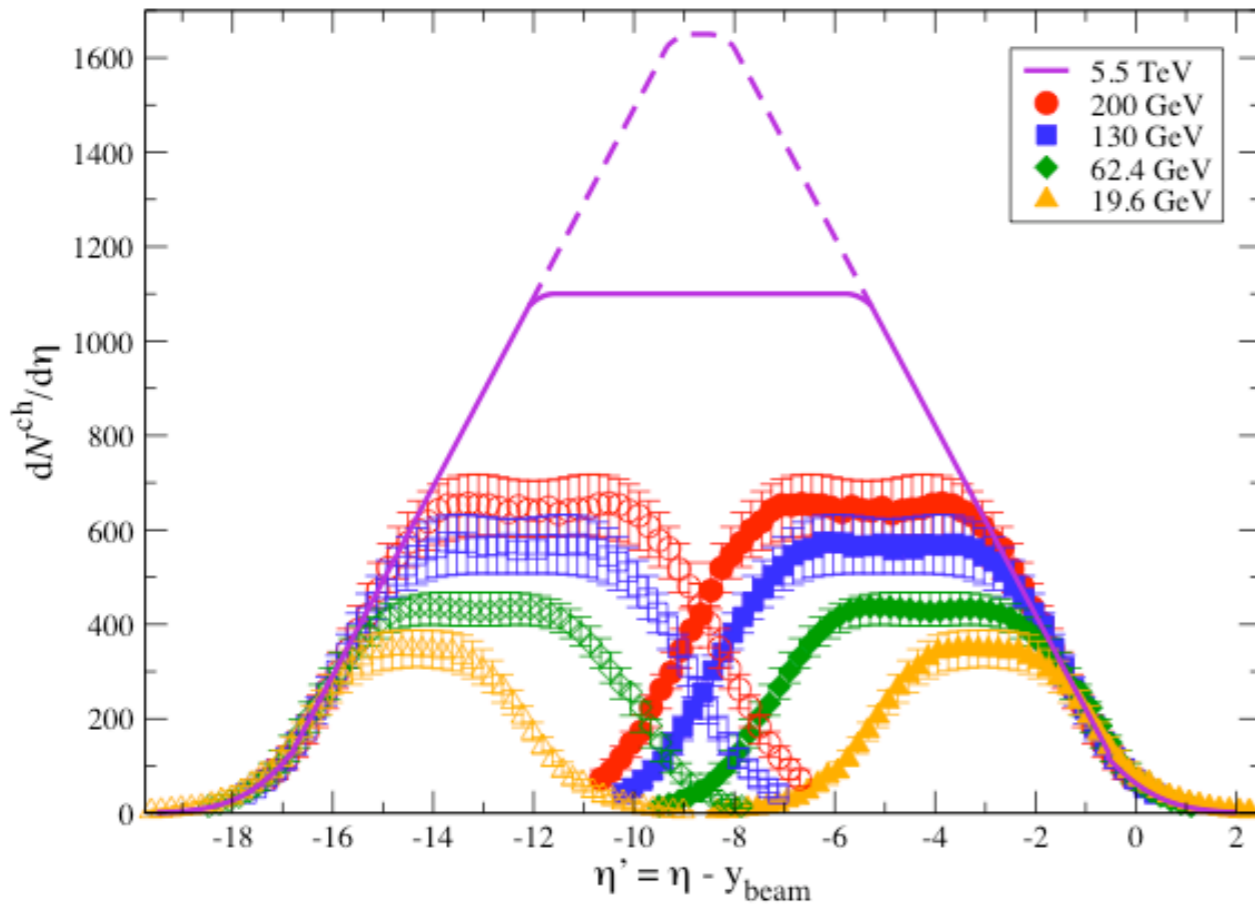
Elliptic Flow, sQGP?



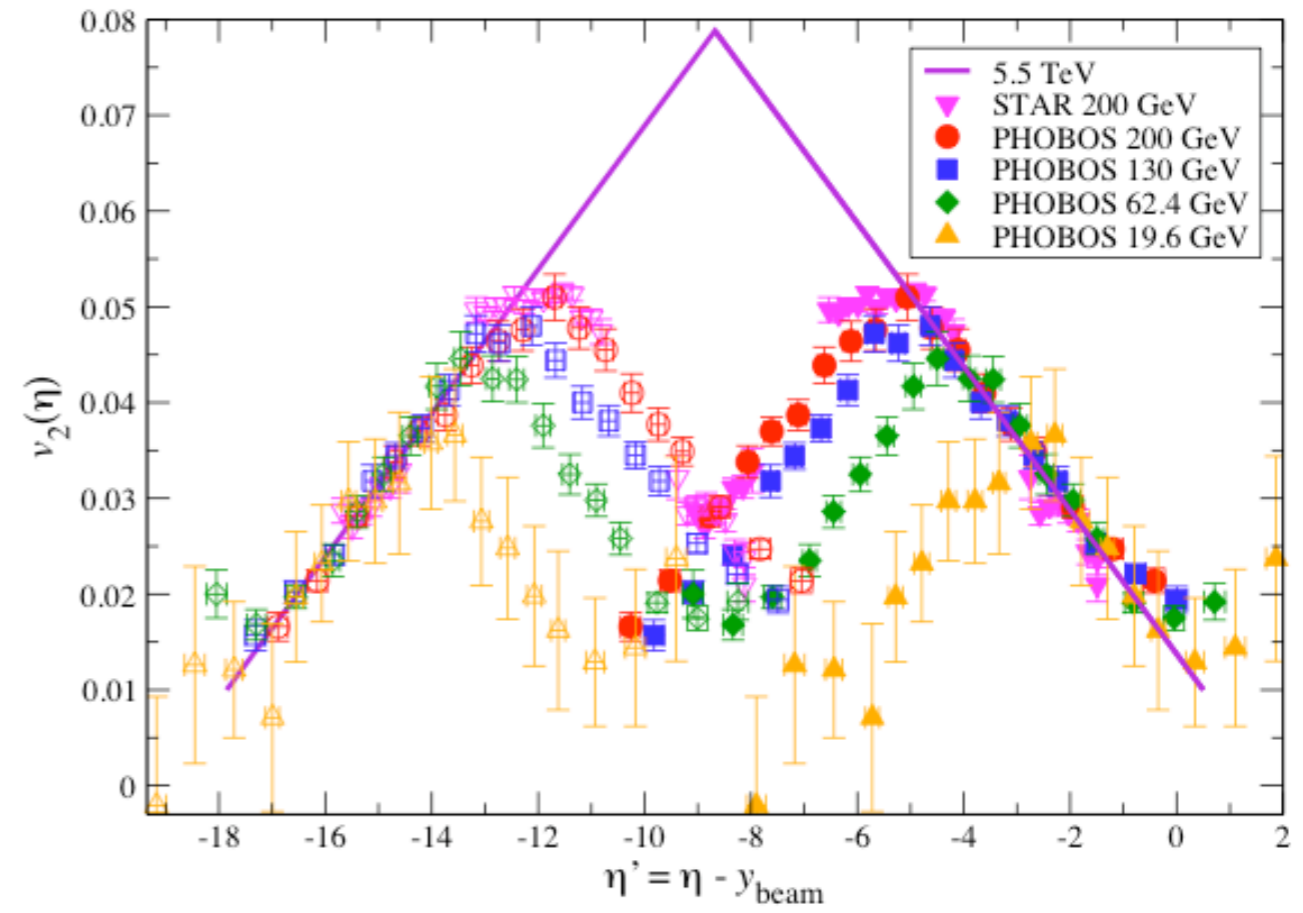
- How strongly coupled is the QGP at RHIC?
 - Need to understand the initial conditions
 - \Rightarrow Accuracy/validity of CGC models?
 - Role of hadronic dissipation for non-central, $|\eta| \neq 0$
- What will happen for x2-3 increase in $\frac{1}{S} \frac{dN}{dy}$?

Persistence of Limiting Fragmentation?

Au-Au collisions 0-6% centrality

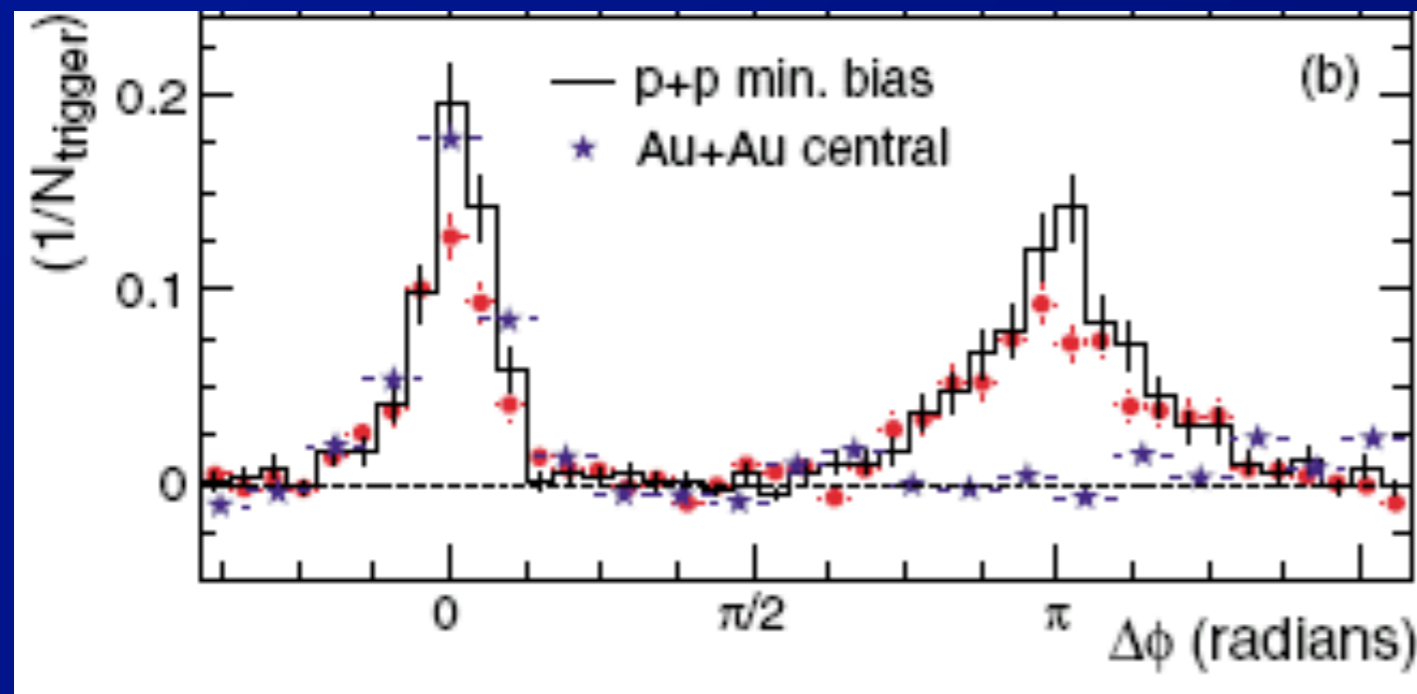
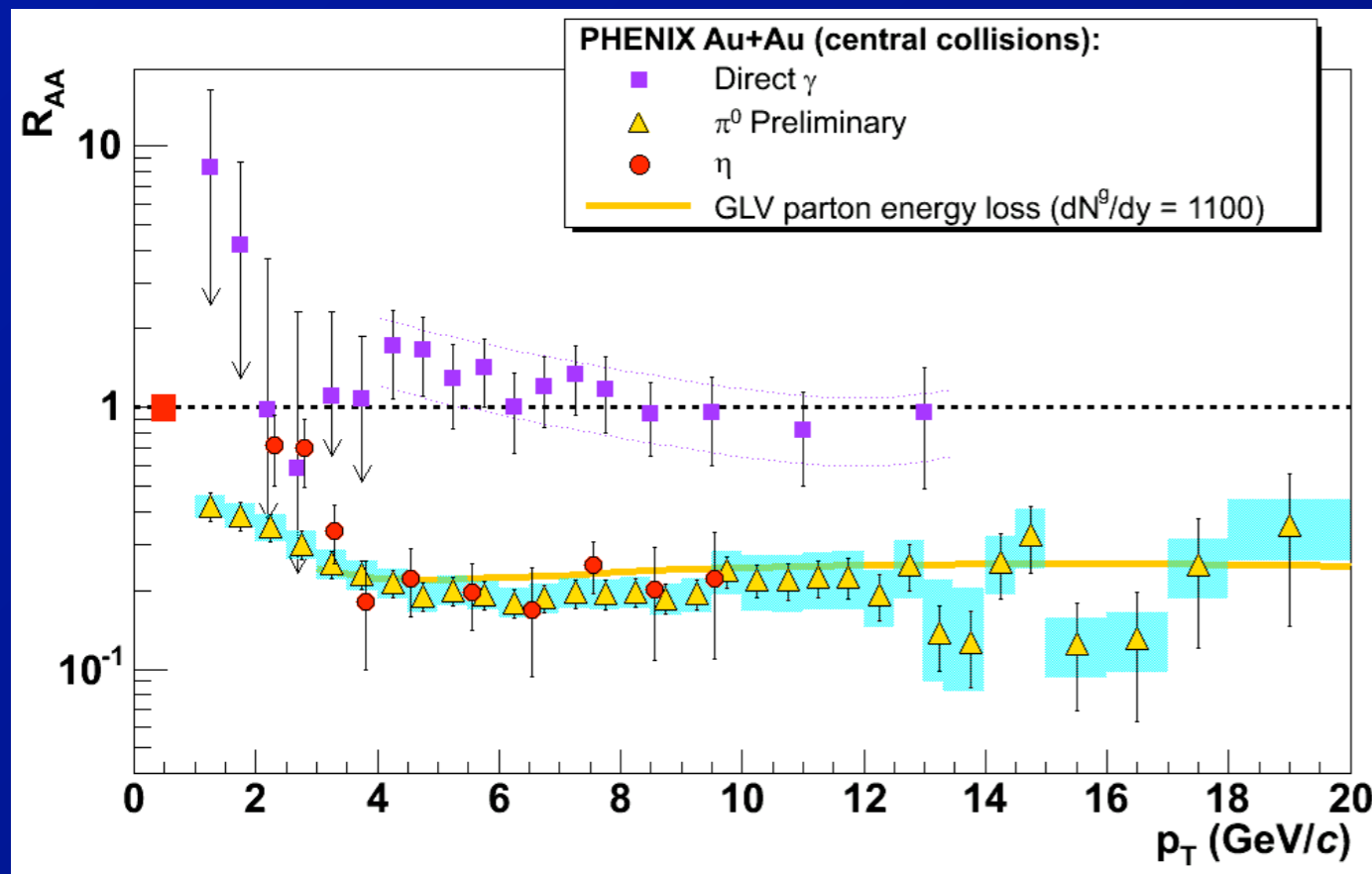


Au-Au collisions 0-40% centrality



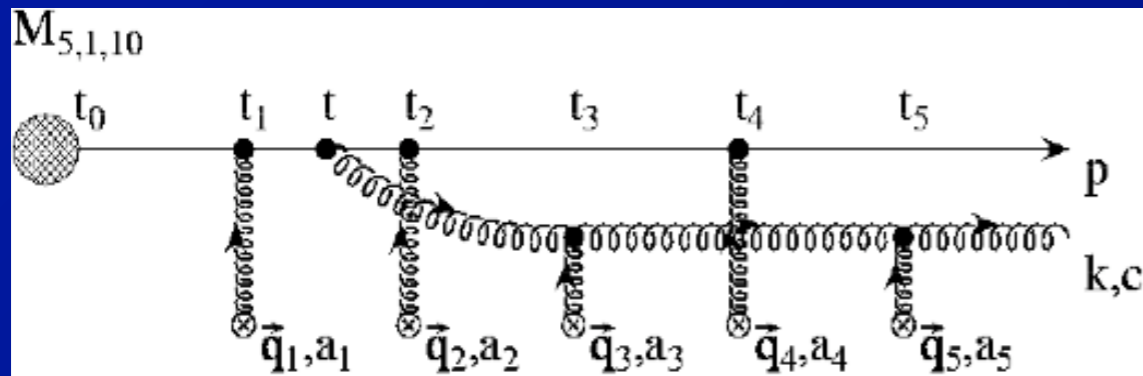
- Measurements at LHC will provide crucial test of limiting fragmentation
 - Persistence will provide serious challenge to our understanding of heavy ion collision dynamics

Jet Quenching



- RHIC has clearly demonstrated the effects of jet quenching.
 - Single jets \rightarrow hadrons
 - Di-jets \rightarrow di-hadrons
- But the mechanism is not understood
 - Radiative dominant?
 - Weakly or strongly coupled?
 - Parton Energy loss vs modified fragmentation

Jet Tomography

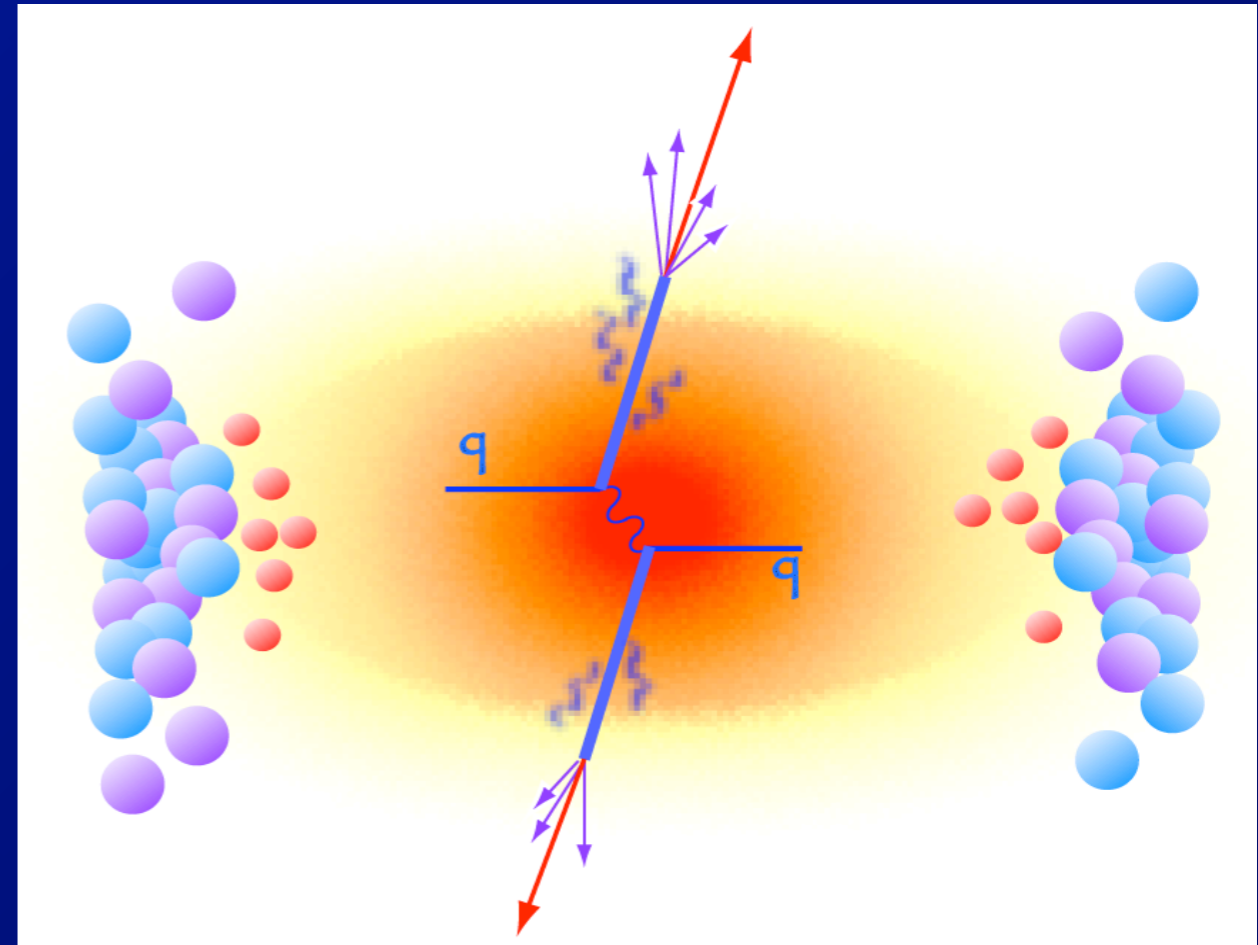


- At RHIC, studied via leading hadrons

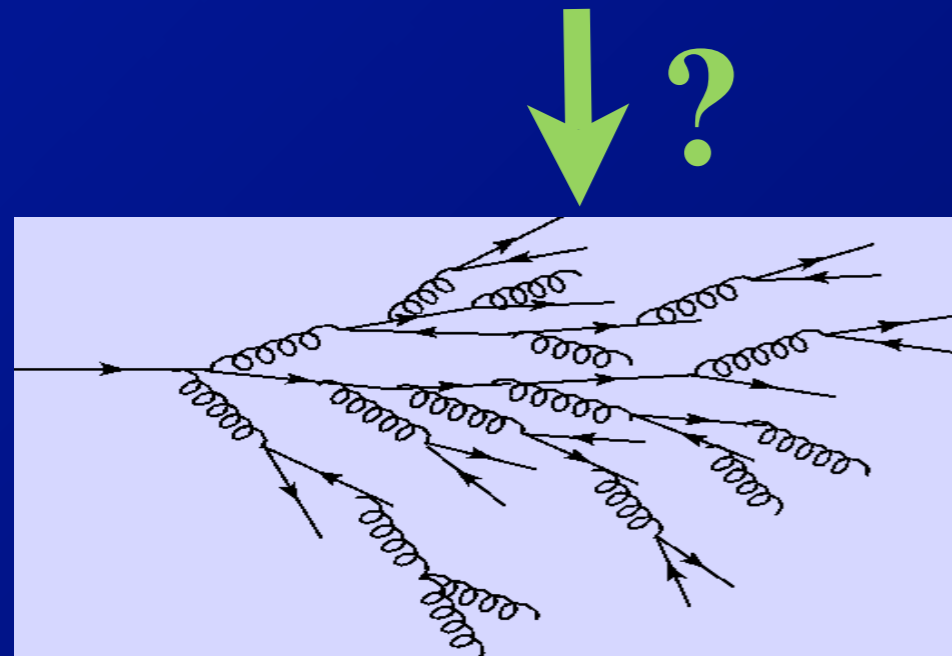
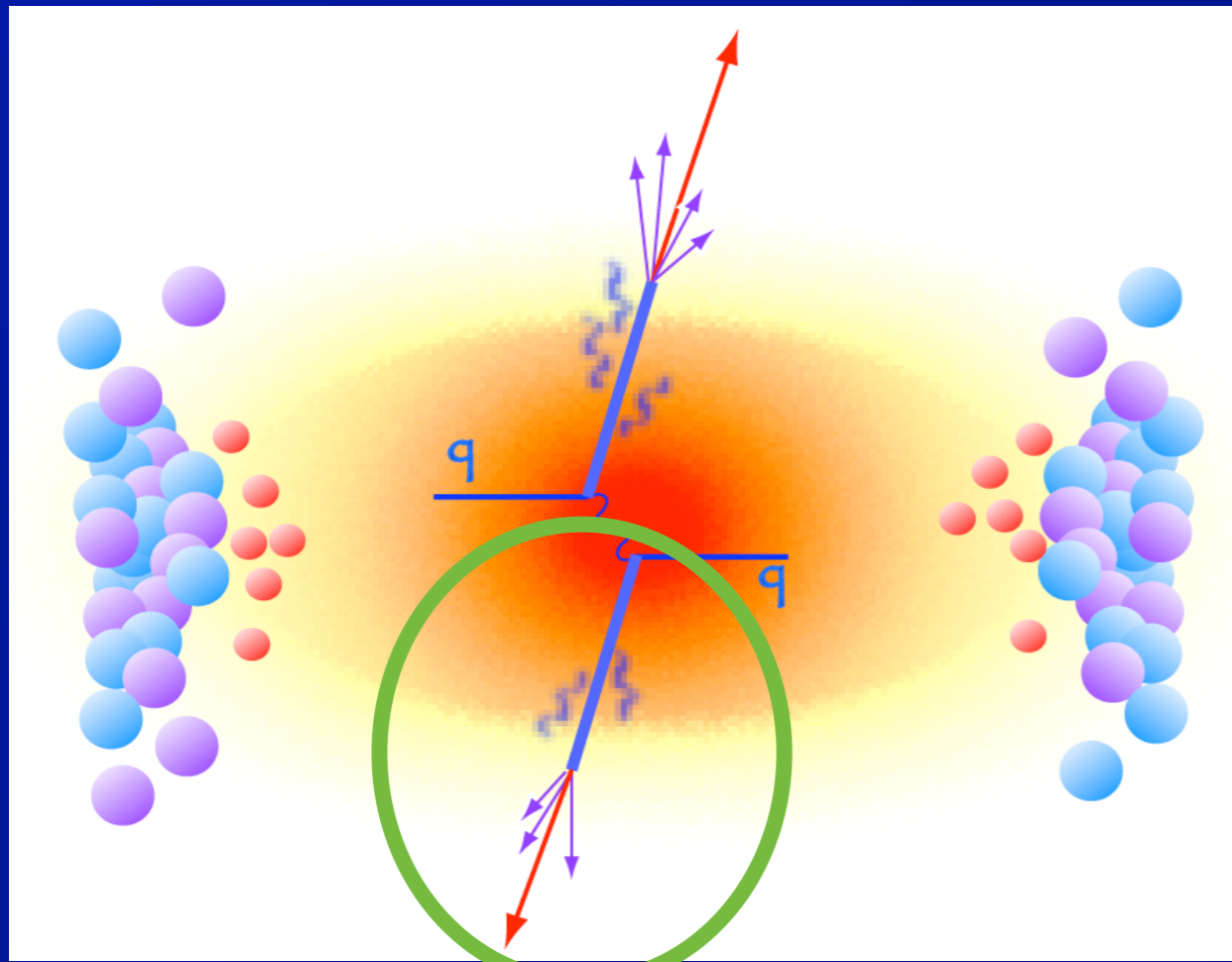
- Statistics suffer from frag. function \Rightarrow rates
- Quenching \Rightarrow geometric bias
- No direct measure of frag. function.

- At LHC:

- Full jets, high p_T , large rates, b jets, di-jet, γ -jet
 \Rightarrow Precision jet tomography



Physics of jet quenching



- **Crucial question:**

- Does parton evolution in medium look anything like a “normal” parton shower?

- **Attempt to distinguish**

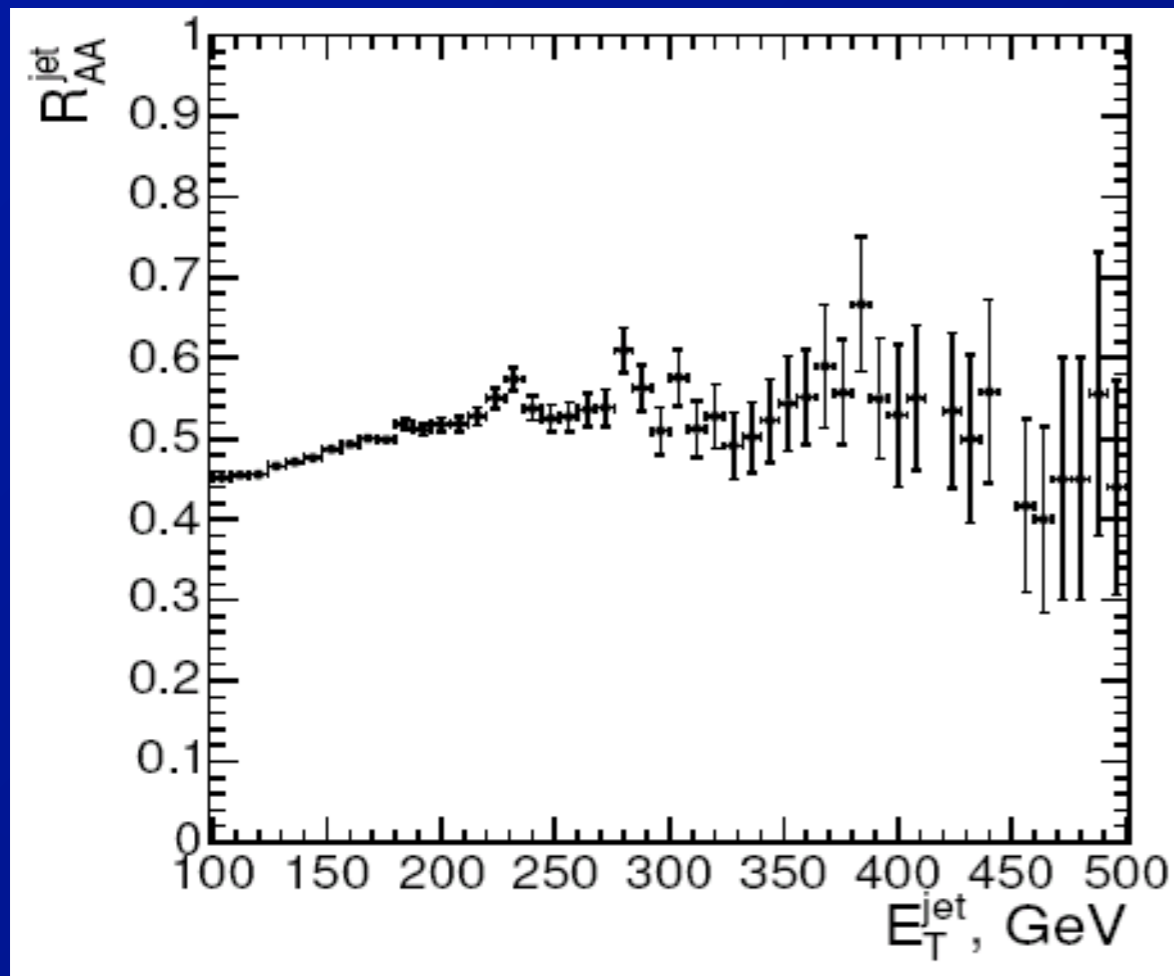
- Weakly coupled radiative + collisional energy loss
- Strongly coupled/non-perturbative quenching

- **Hard to tell looking only at hadrons**

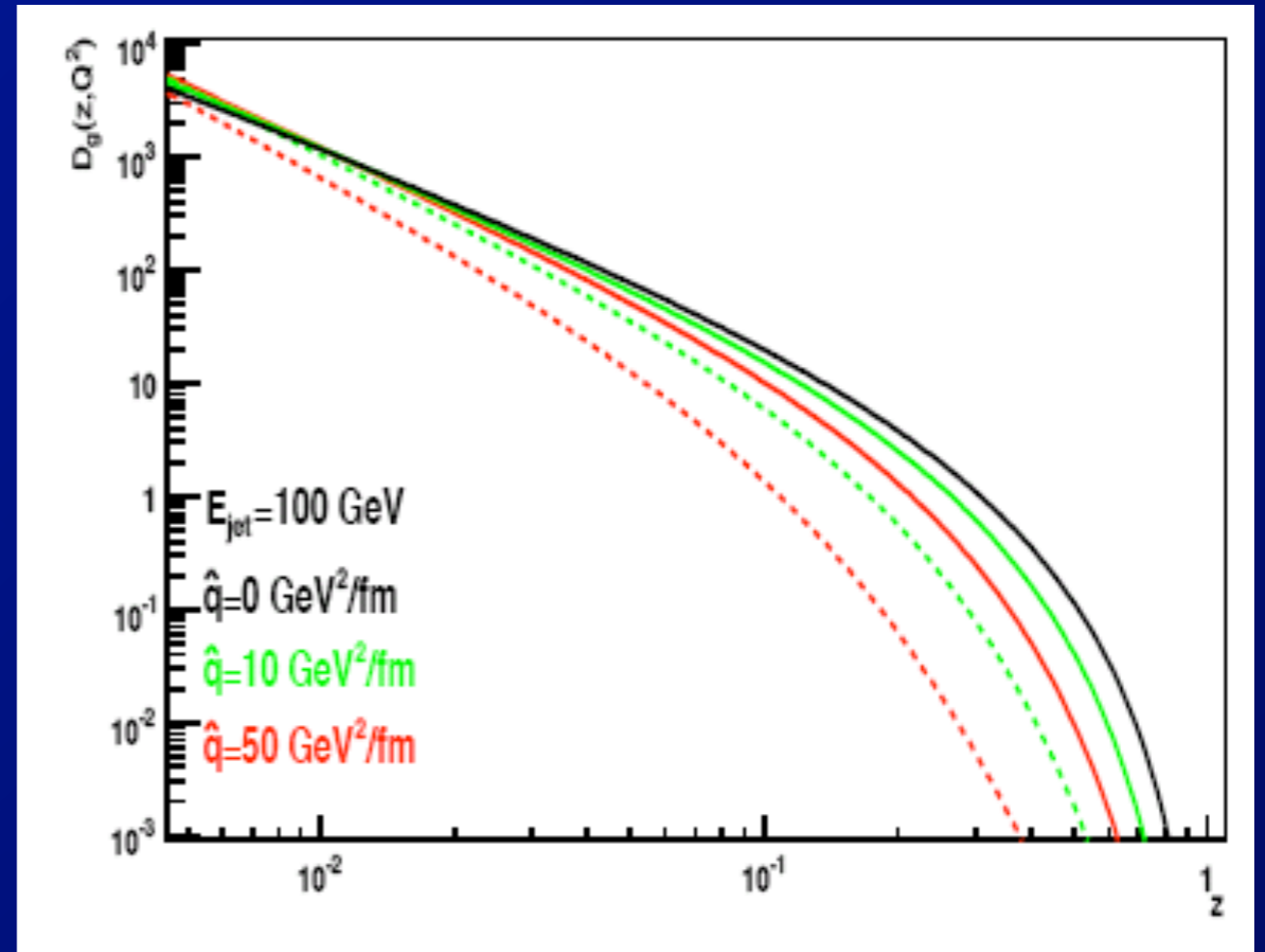
- Need to see jet (or not!)

Probing jet quenching mechanisms

Jet R_{AA} (Lokhtin et al)



Modified Frag. Func., (Armesto et al.)



- Jet R_{AA}

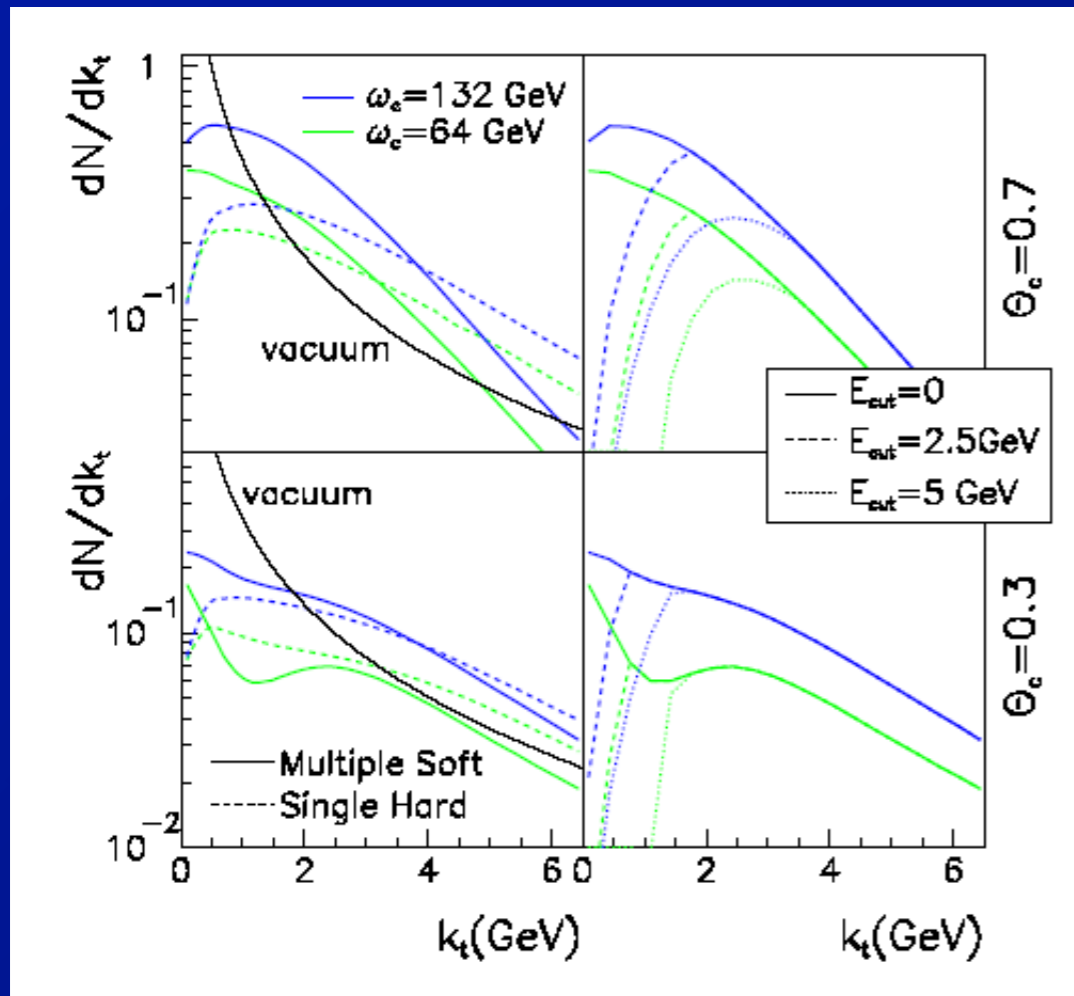
- Non-perturbative/strongly coupled quenching
- Collisional energy loss, radiation outside jet

- Modified fragmentation functions

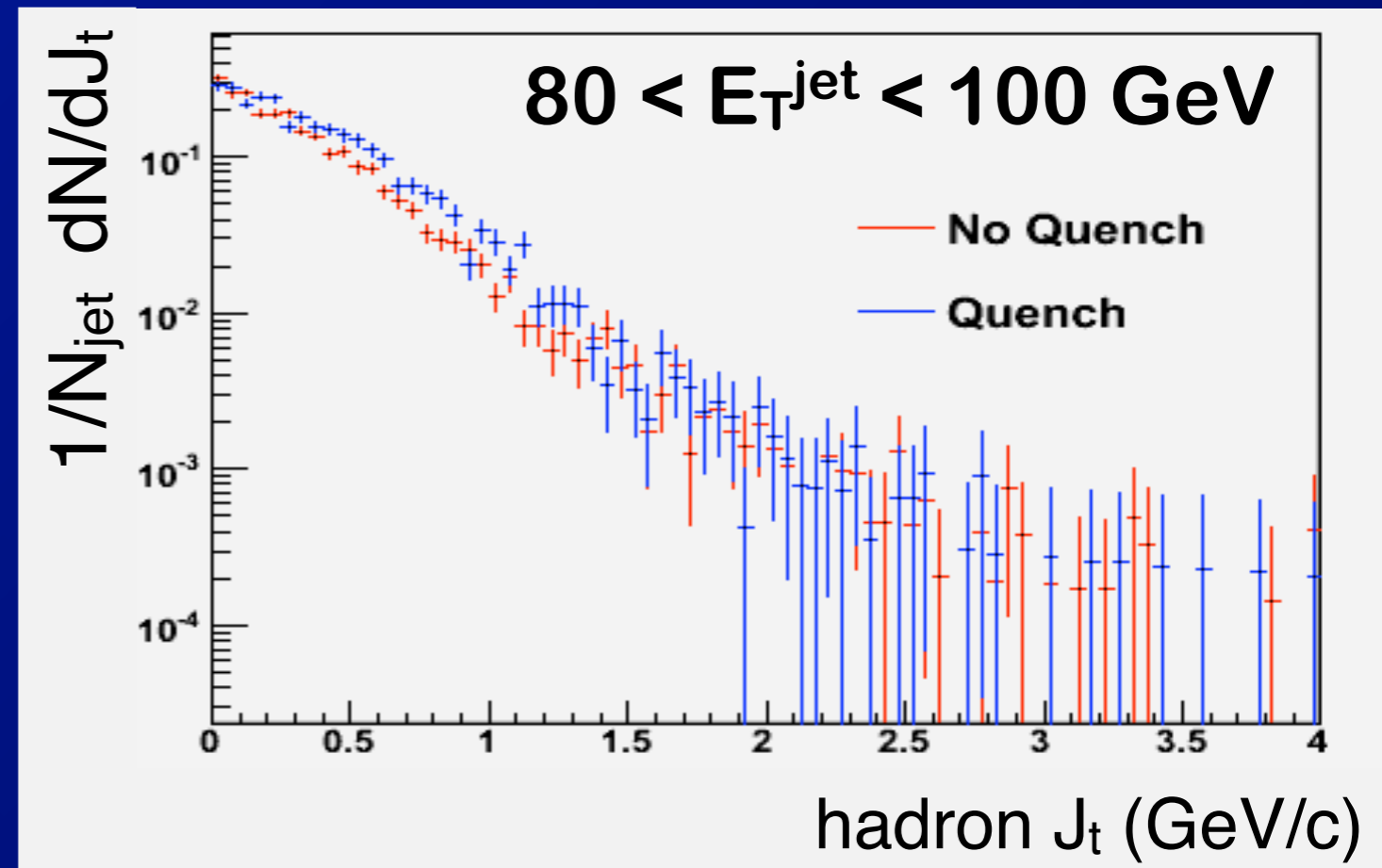
- Radiative energy loss (inside jet)

Jet Broadening

k_T “broadening” (WS)

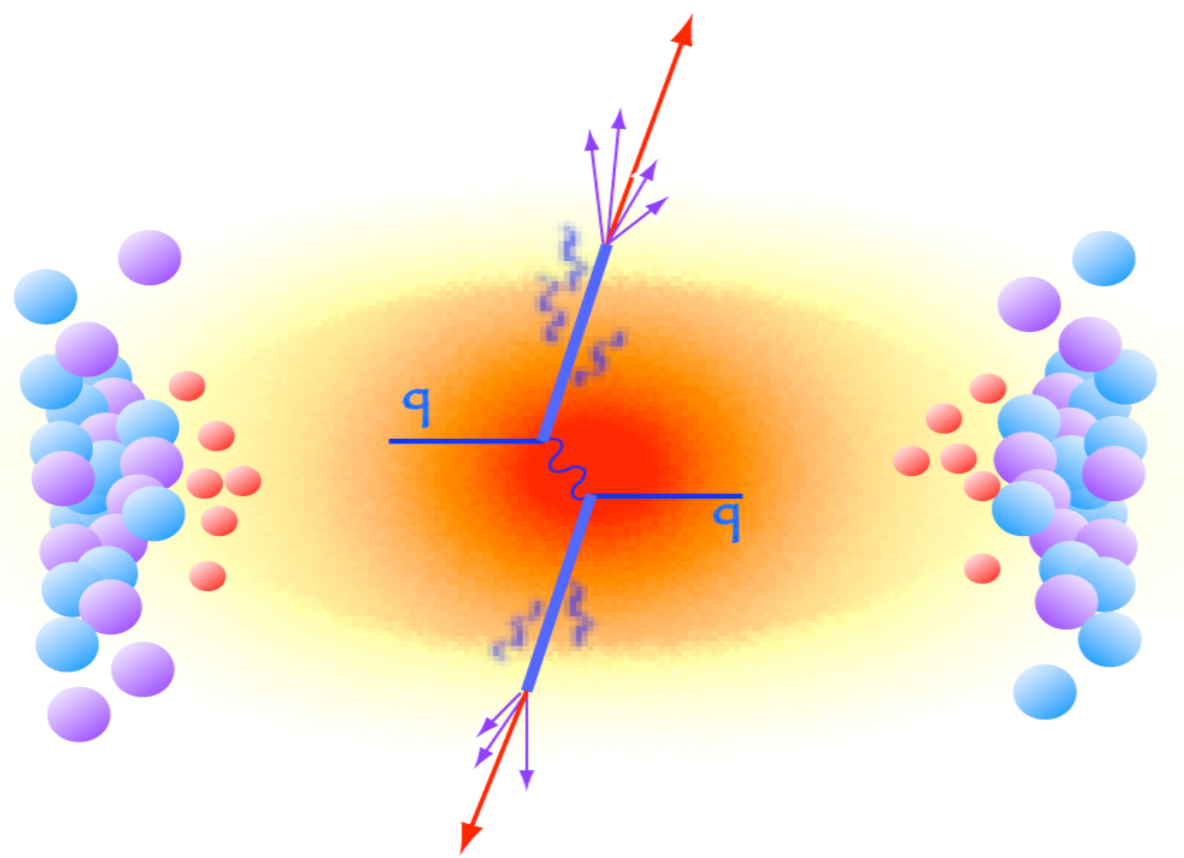


Pyquench, Central Pb+Pb

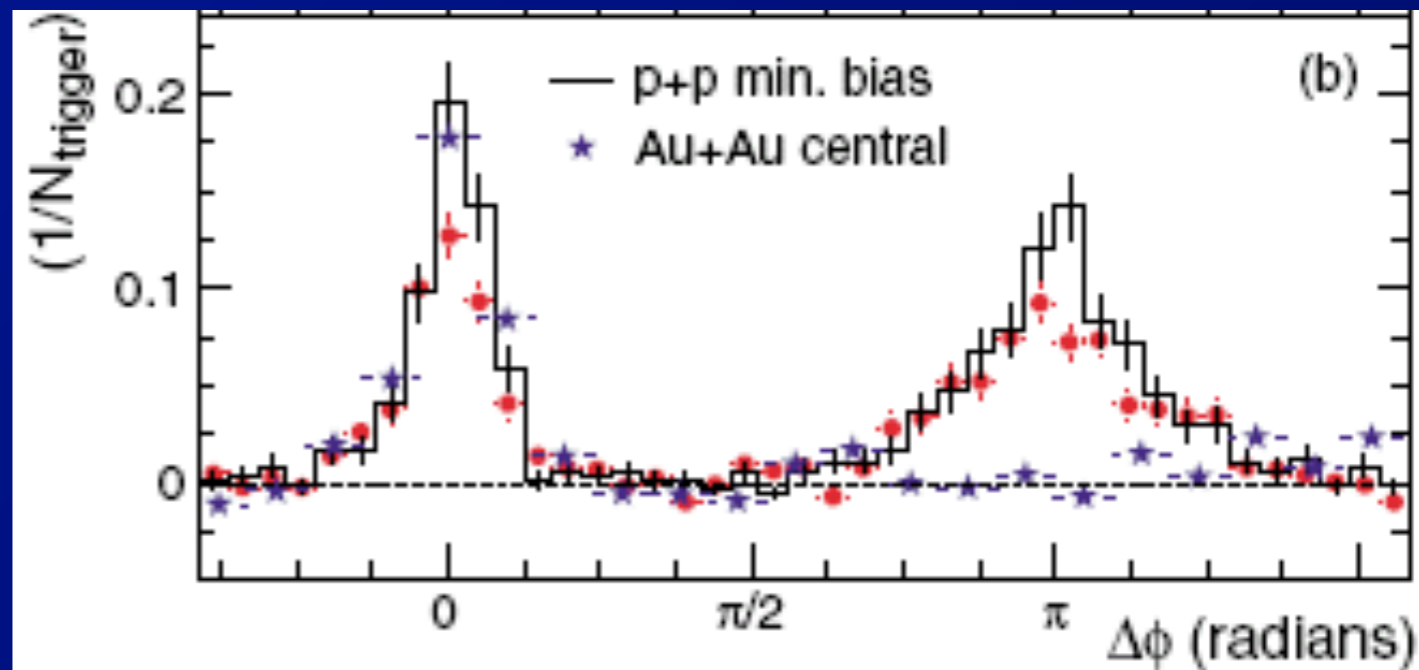


- Important jet fragmentation observable
 - Modest change in hadron J_t distribution for weakly coupled jet quenching.
 - Weakly coupled quenching (as implemented in Pyquench) modest perturbation to parton shower.

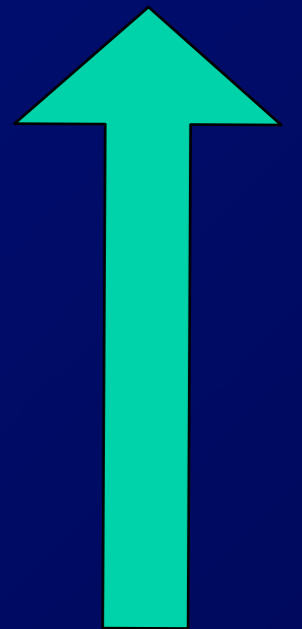
Di-je/Multi-jet final states



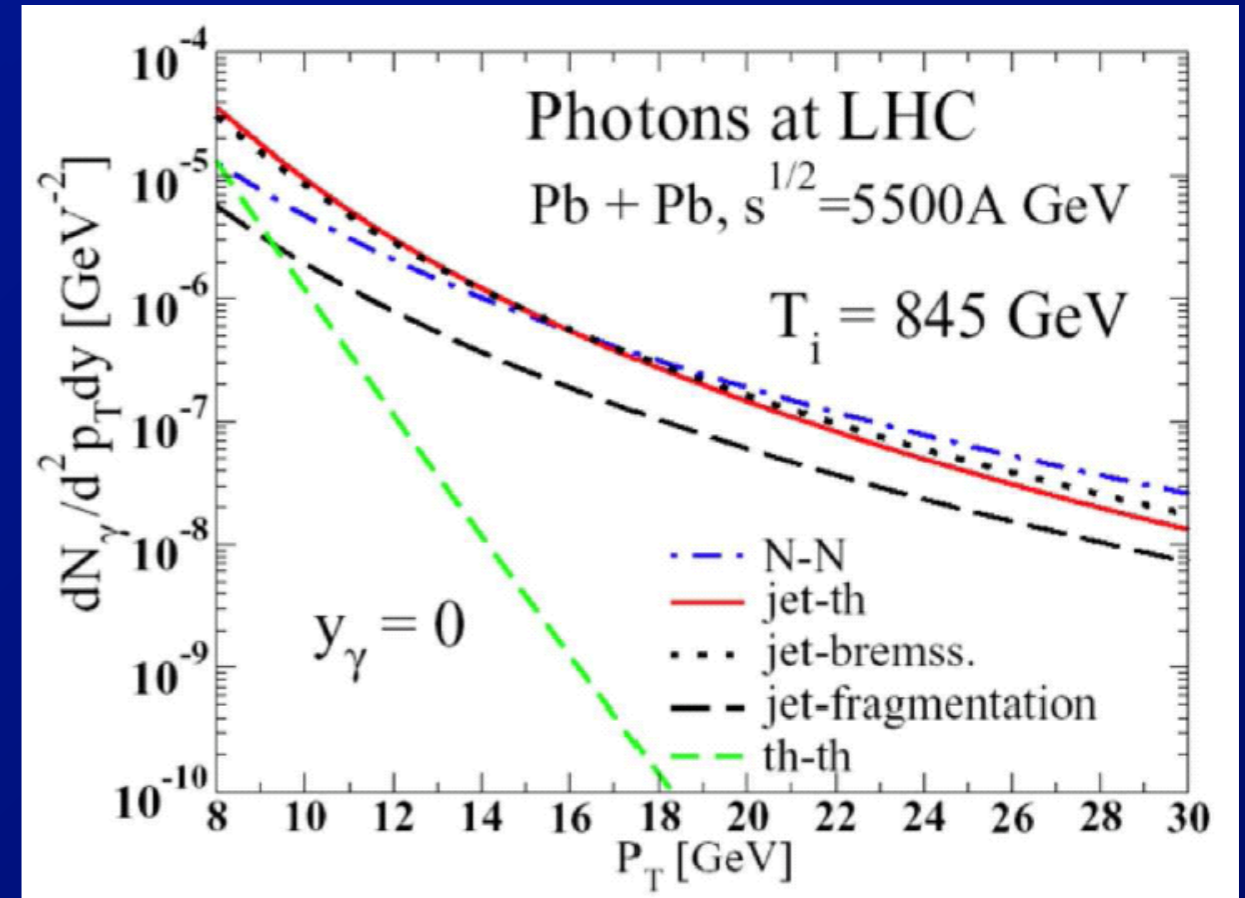
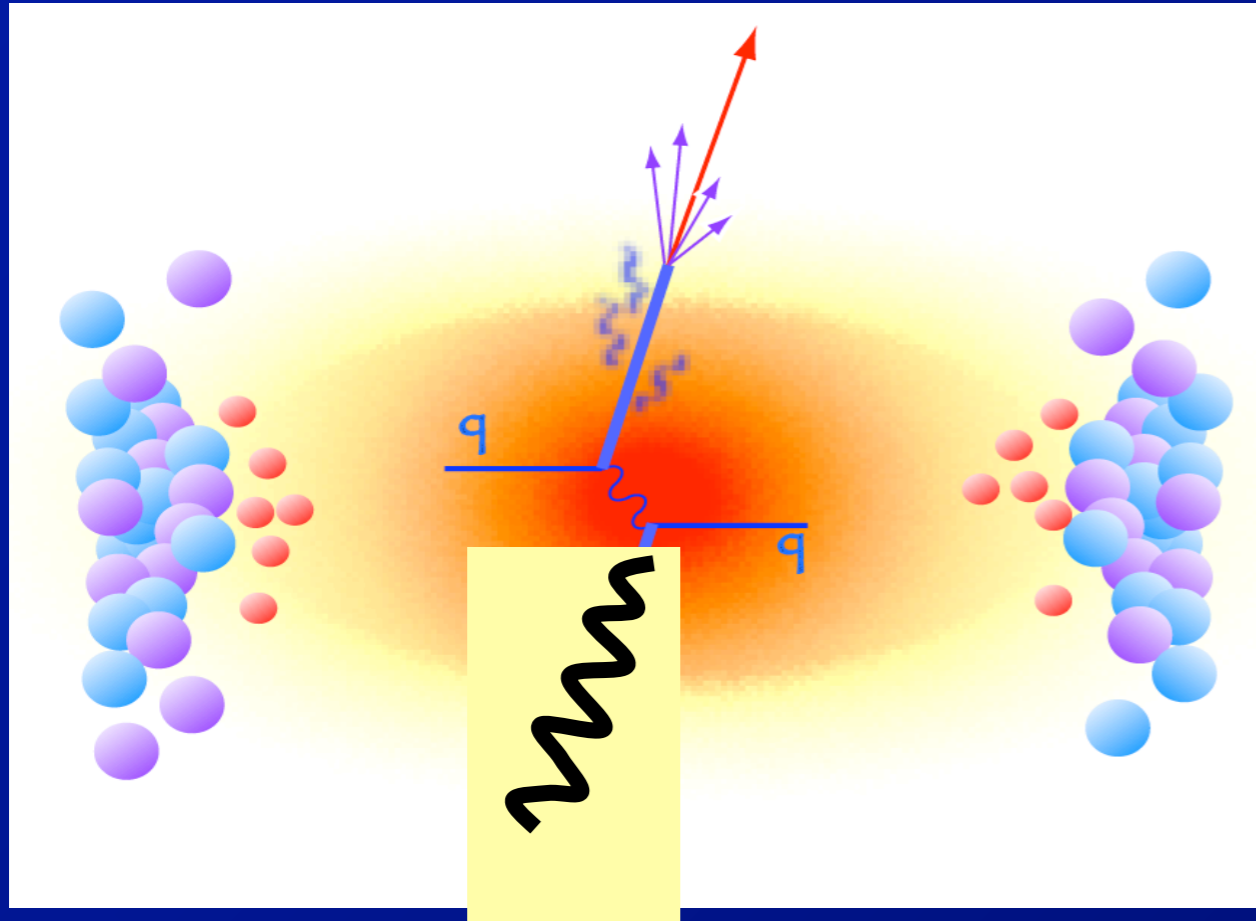
Suppose this happens with fully reconstructed jets too?!



- **Test for weakly coupled jet quenching:**
 - Persistence of di-jet/multi-jet final states.
 - \Rightarrow Possibly broadened
 - \Rightarrow With energy imbalance
- **But, with (e.g.) Dima's strongly coupled quenching we might see something more like**

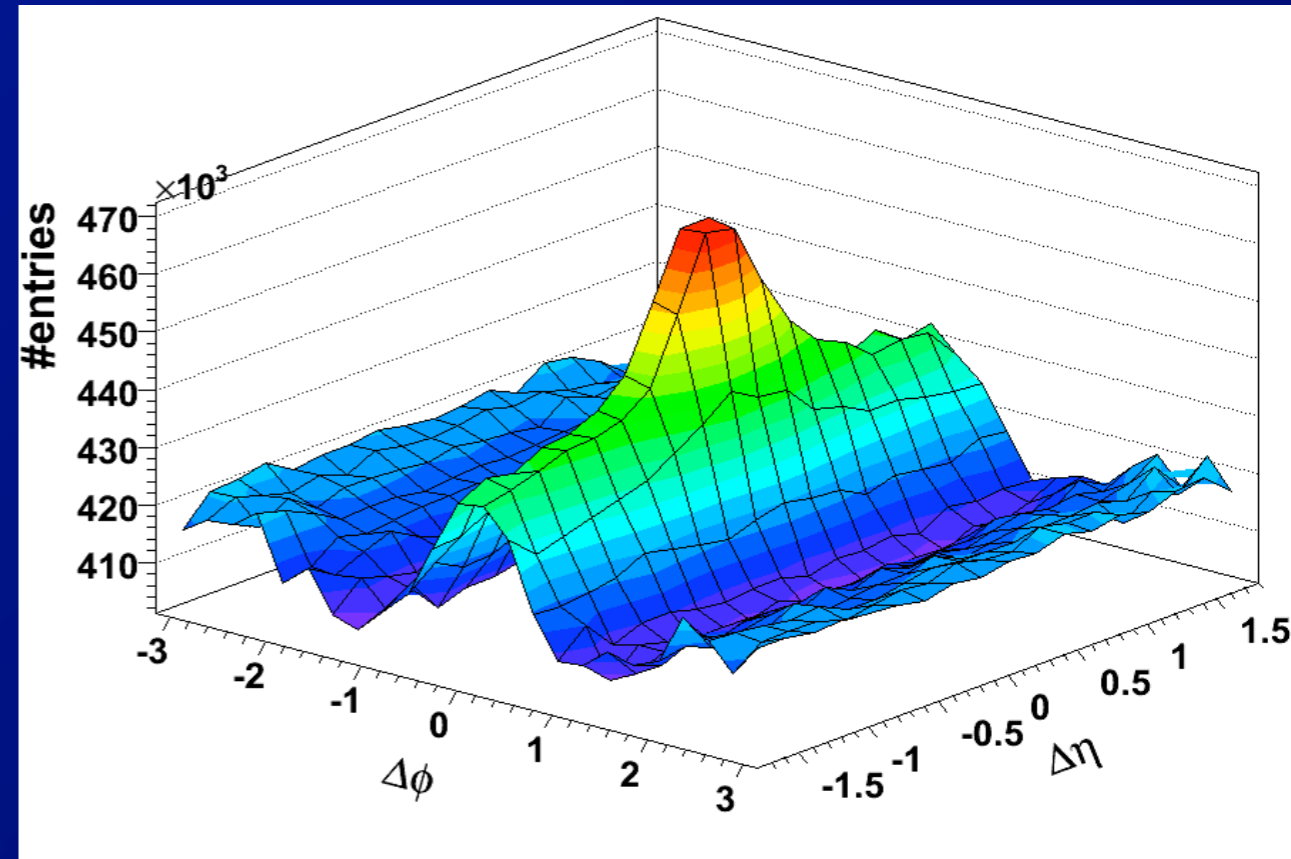
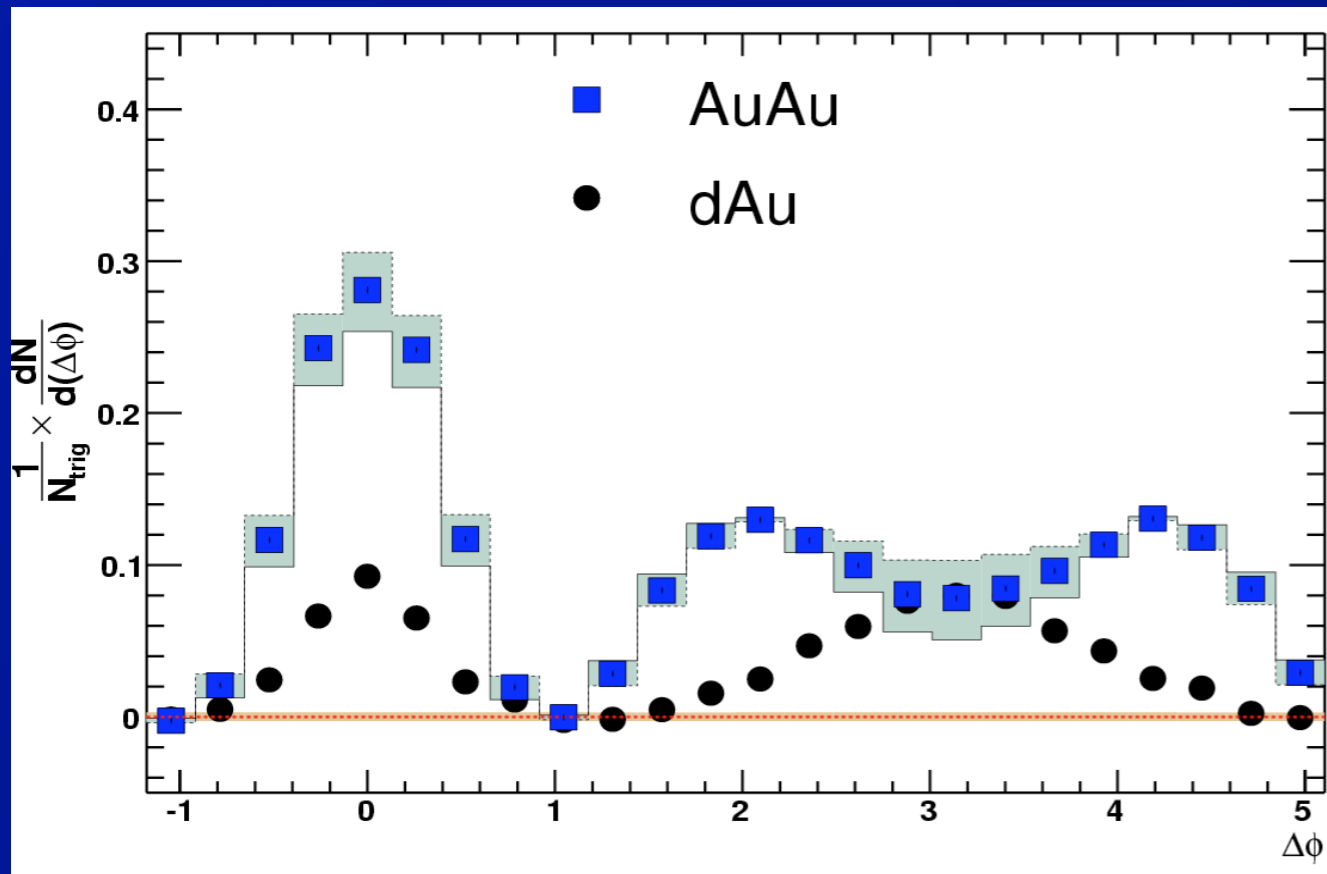


Prompt photons and γ -jet Prompt photons



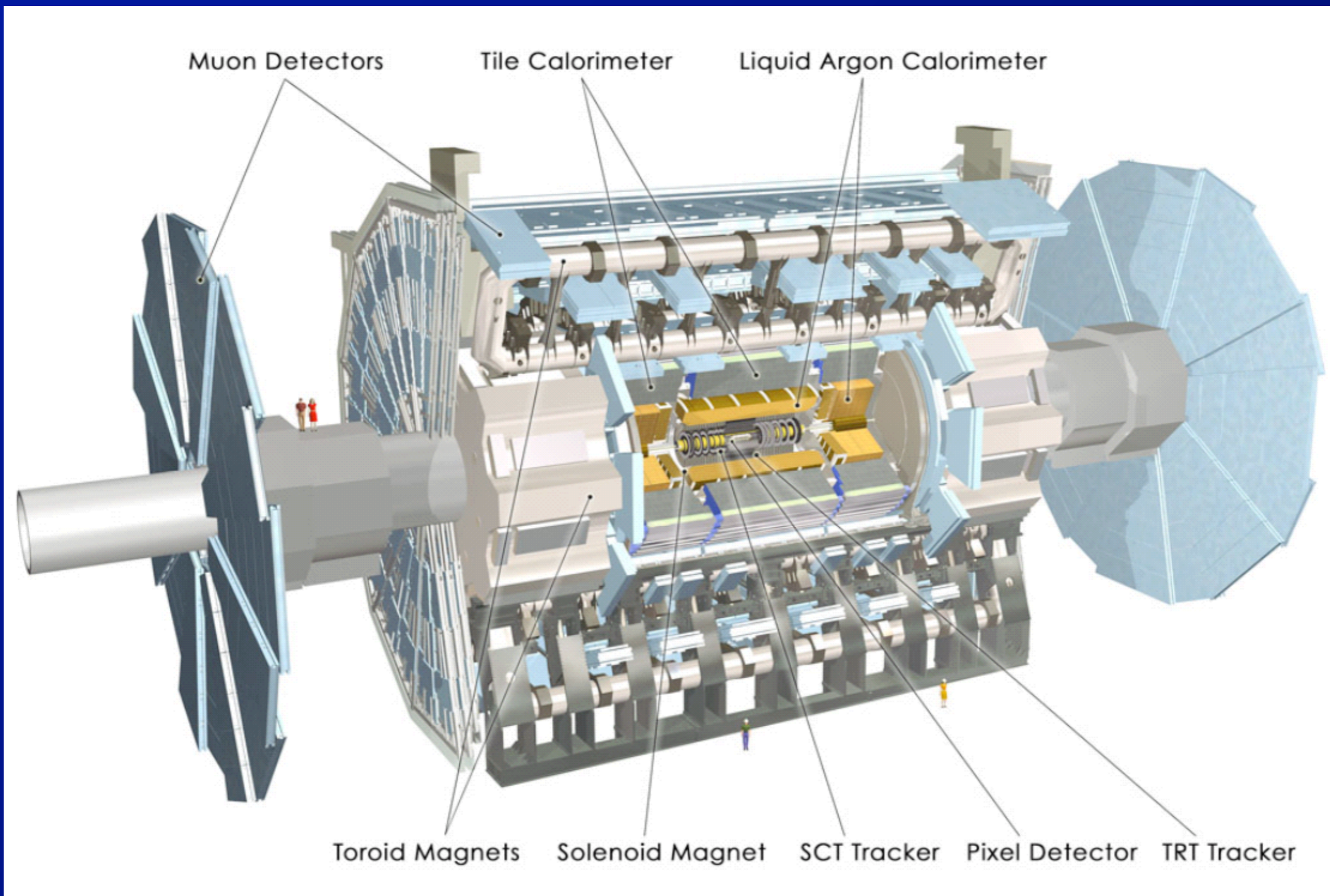
- I don't need to tell you that γ -jet is important
 - Beware simplistic view, **NLO and parton cascade**
 - Can be reduced with cuts, but throws away physics
- Other prompt photon contributions important
 - Fragmentation & bremsstrahlung in jets (~~isolation~~)
 - Jet conversion – critical probe of medium.

Medium Response



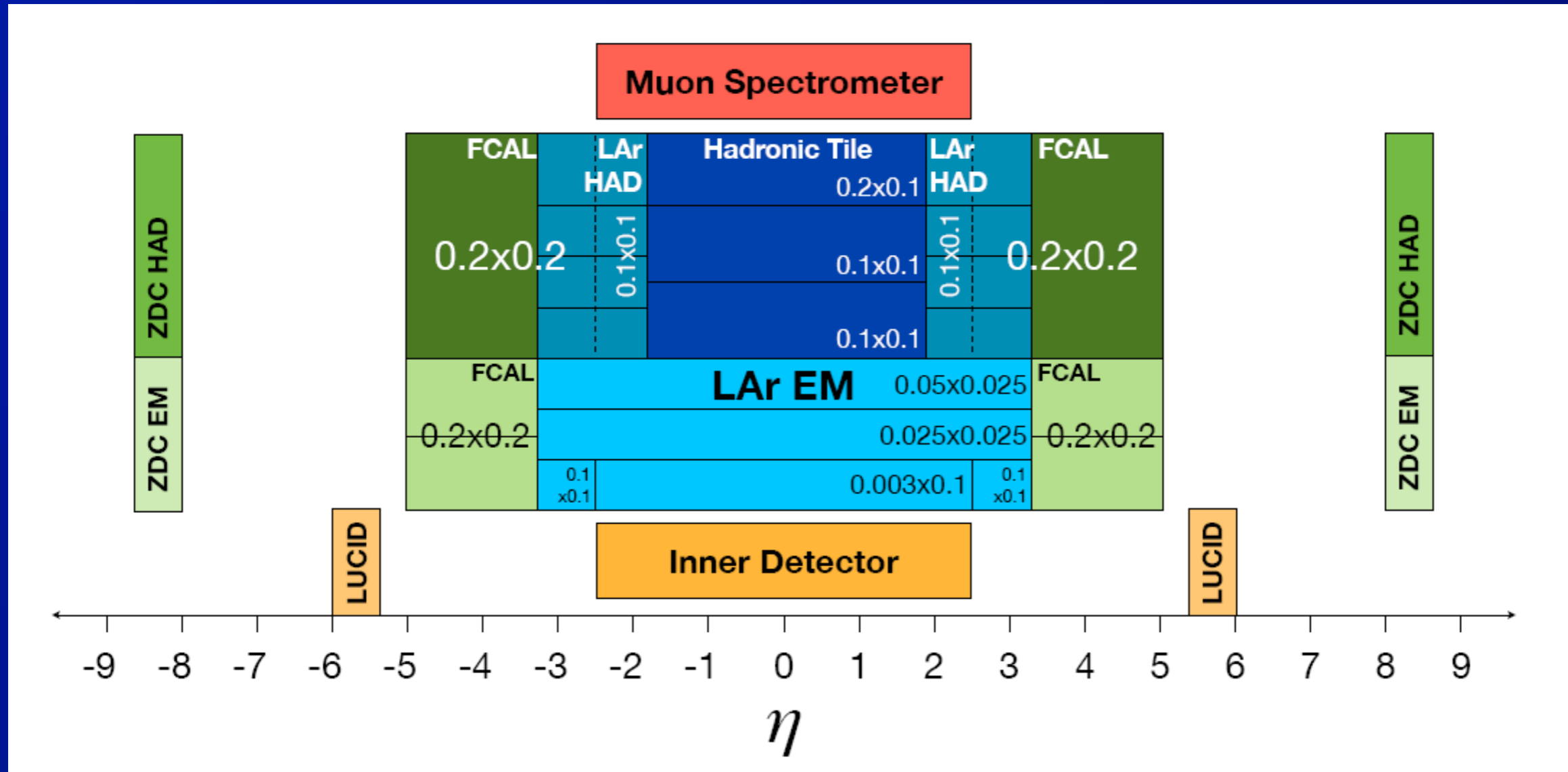
- Nature is trying to tell us something
 - We just don't know what (yet)
- Suppose we could do these same measurements -- but for 100 GeV jets
 - Instead of ~ 5 -10 GeV/c hadrons
 - With \sim complete η coverage.

The ATLAS Detector: Schematic



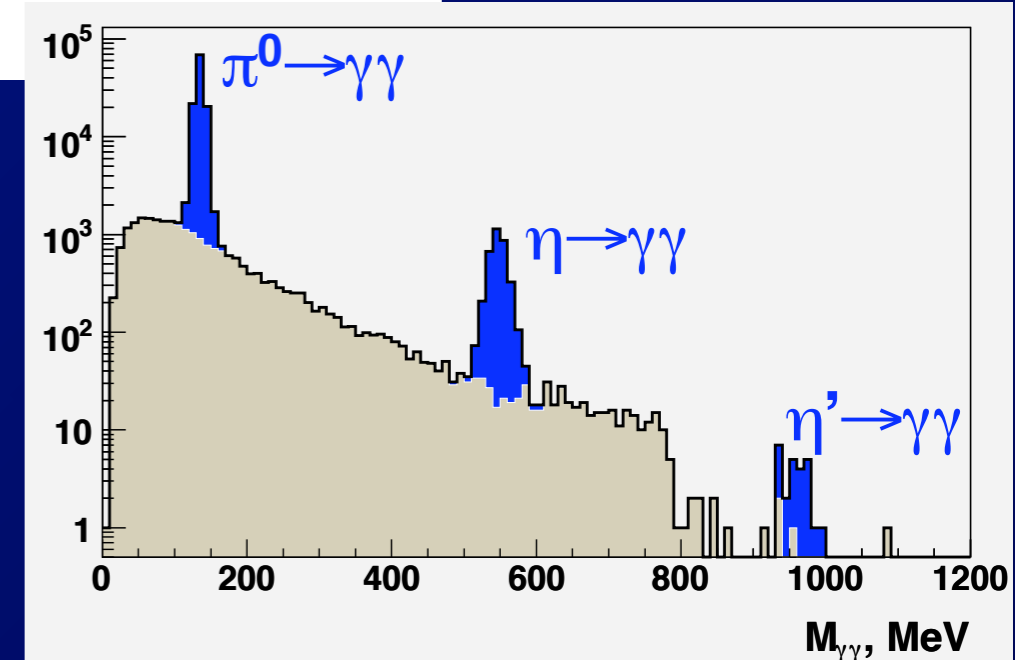
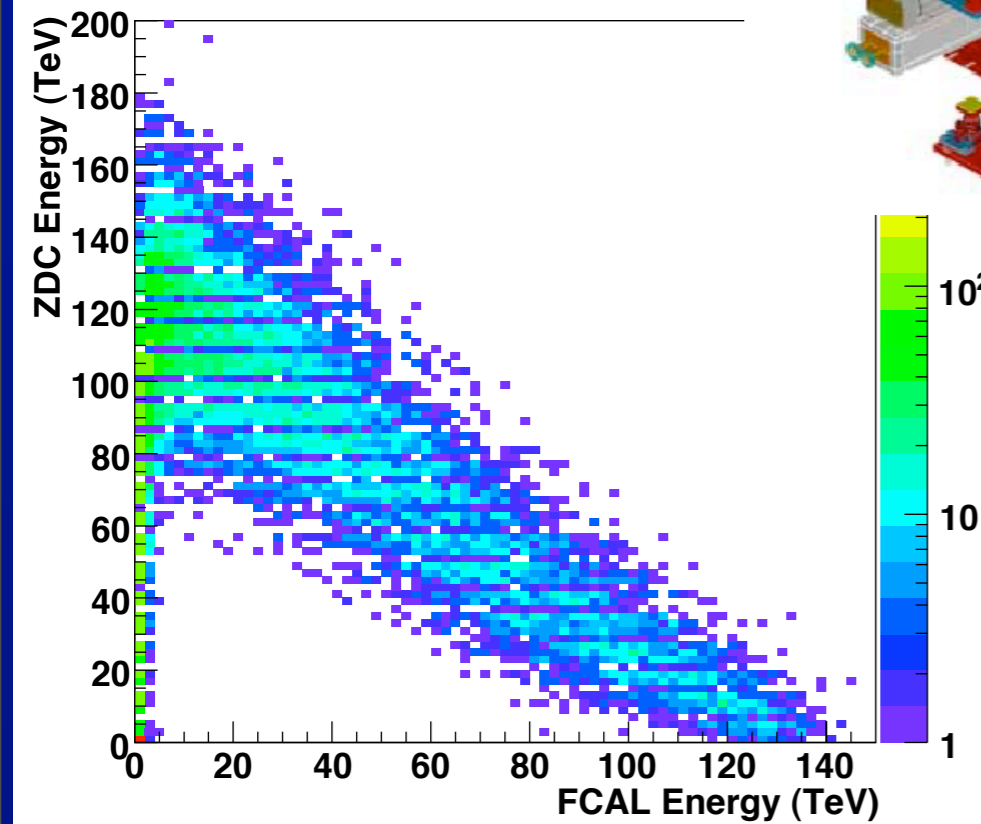
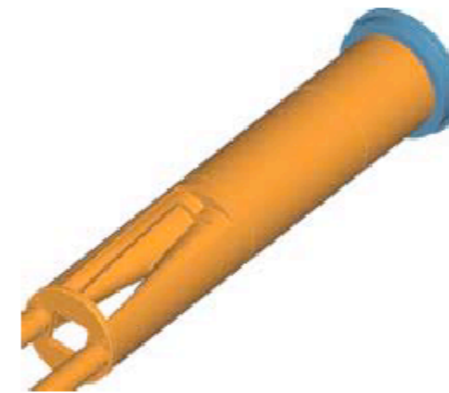
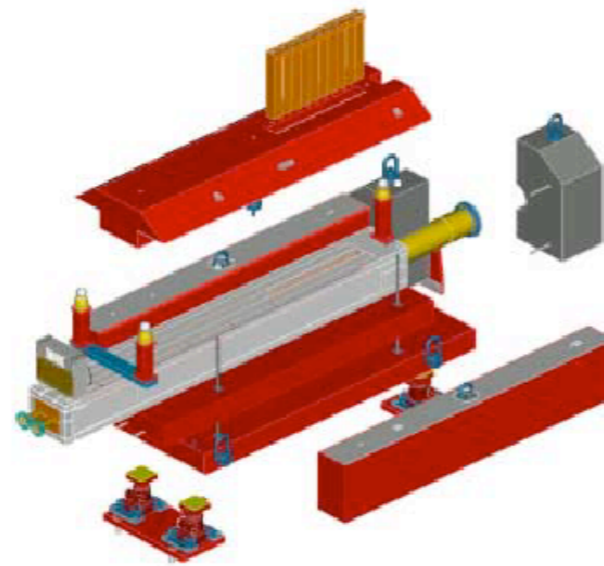
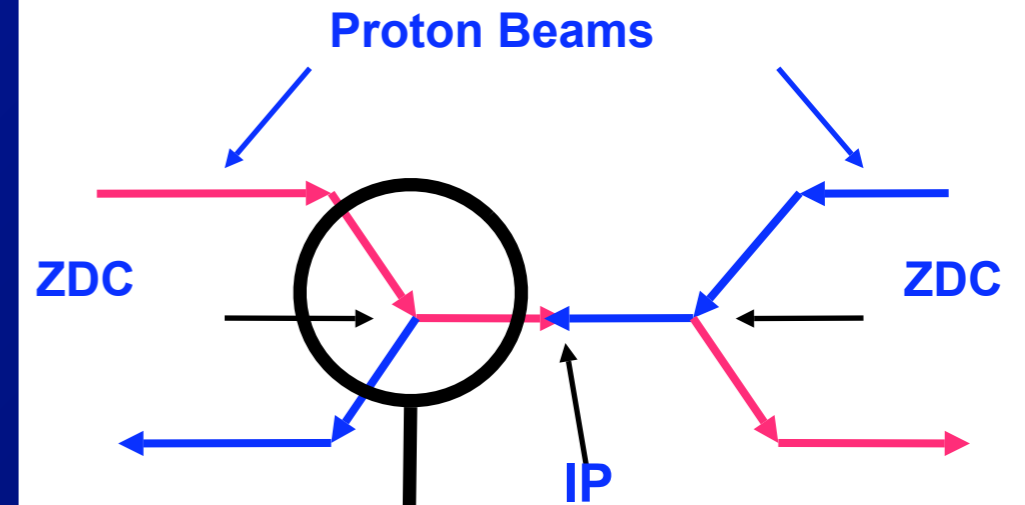
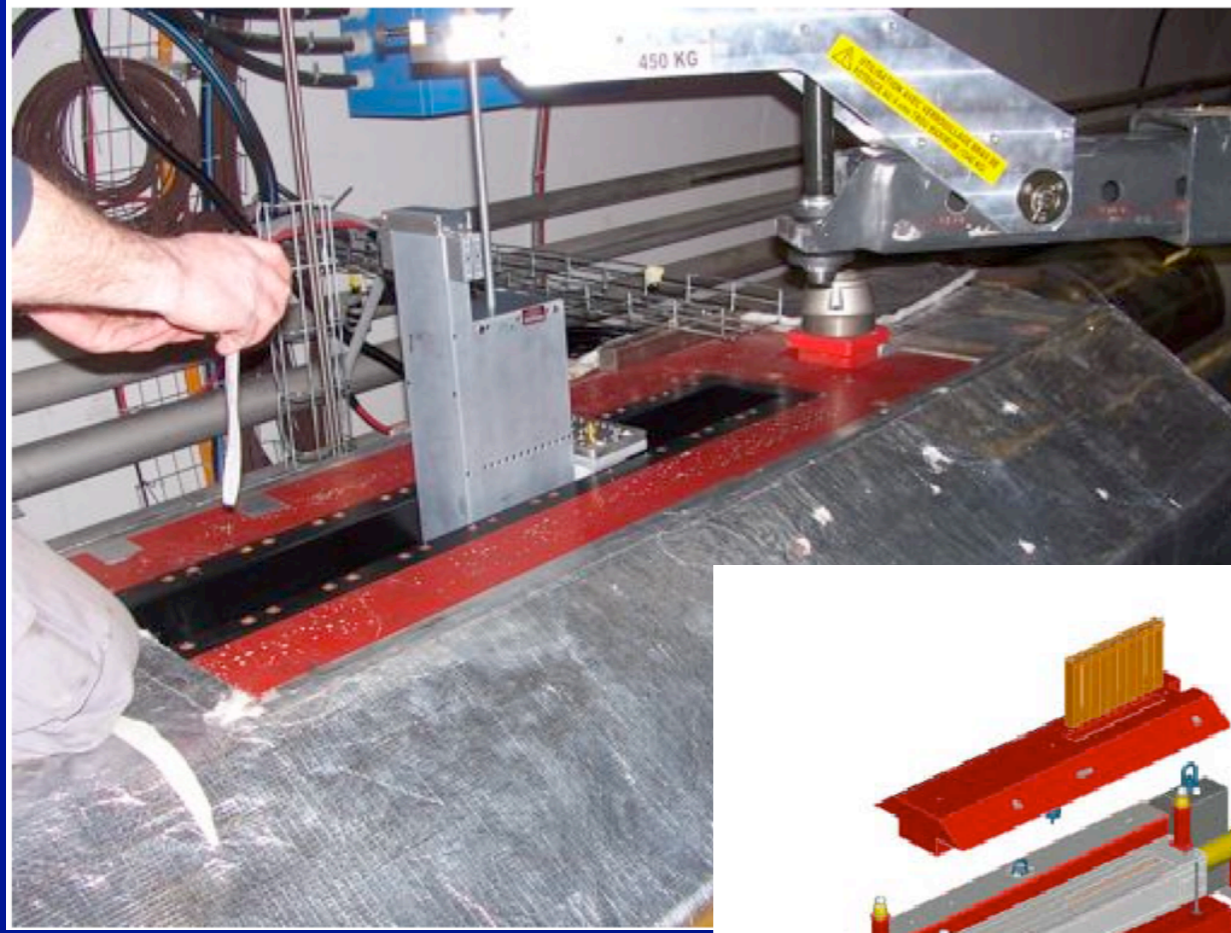
Ideal for measuring jets, jet fragmentation, photons, (di)muons, global observables over wide η range.

ATLAS Acceptance



\longleftrightarrow Bulk observables
 γ , π^0 , isolated γ
 \longleftrightarrow Y , Y'
 \longleftrightarrow Jets

ATLAS Zero-degree Calorimeter

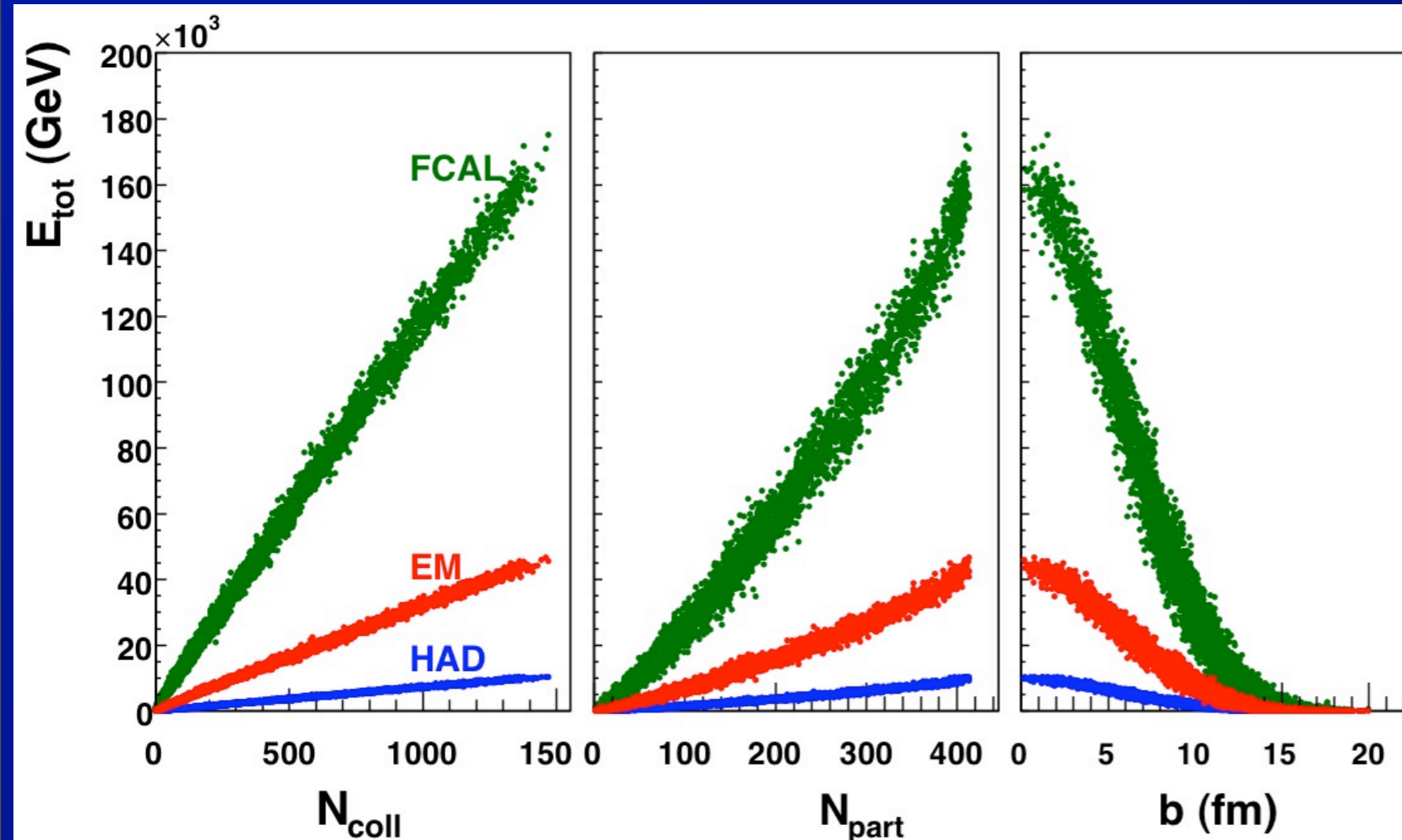


ATLAS Heavy Ion Program

Primary Physics Goals

- Measure multiplicity, $dN/d\eta$, $dE_T/d\eta$, v_2 over $|\eta| < 6$.
⇒ Initial particle production, early collectivity
- Study jet quenching via full jet measurements
 - Jet R_{AA} , modified $D(z)$, di/multi-jet correlations
 - Tagged heavy flavor jets
 - Measure medium response w/ jet tags over $|\eta| < 6$
- Direct photon production with/without isolation
 - Single γ spectrum, γ -jet events
 - Fragmentation/bremsstrahlung, jet conversion γ
- Quarkonia production/suppression (esp. Υ , Υ' , Υ'')
- Low-x physics in p-p, p-A

Centrality Measurement

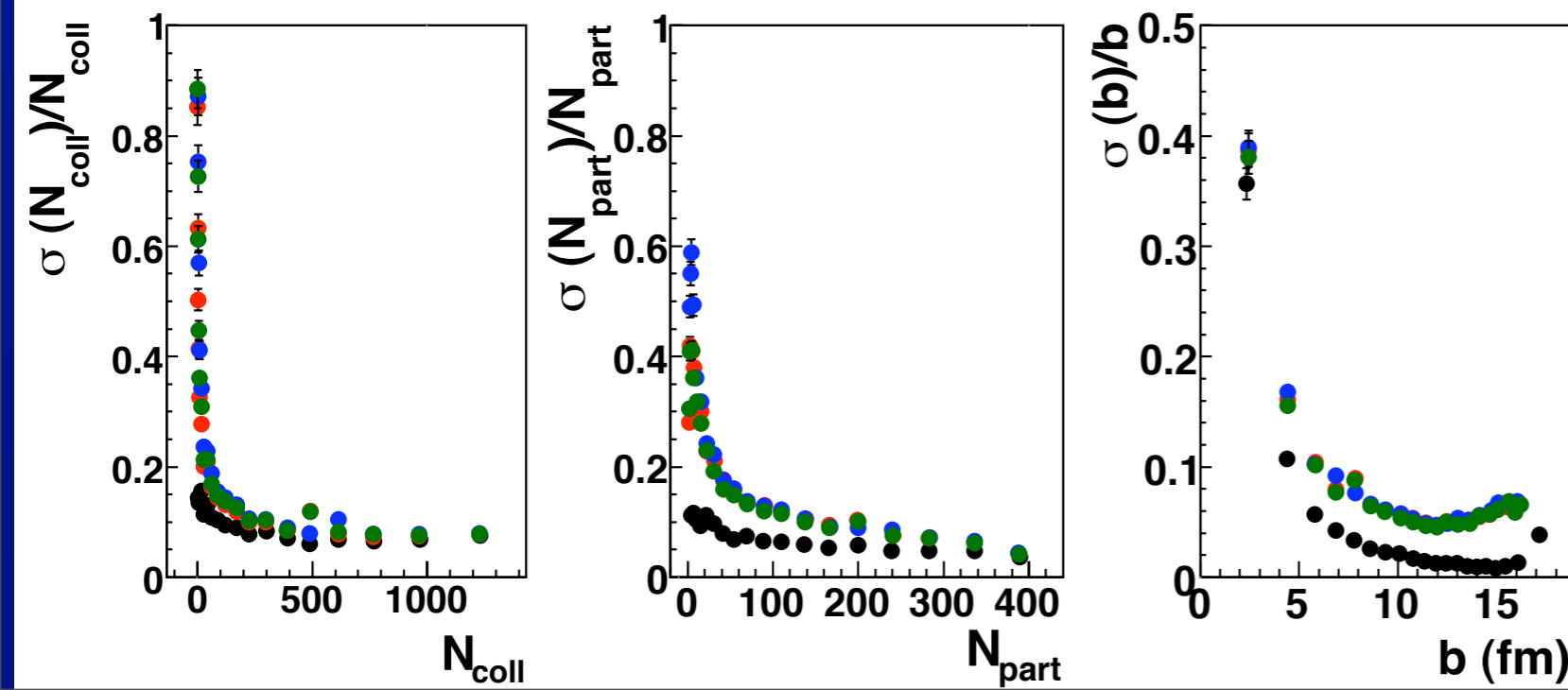


• Example centrality measurement via calorimetry.

– High multiplicity, large acceptance

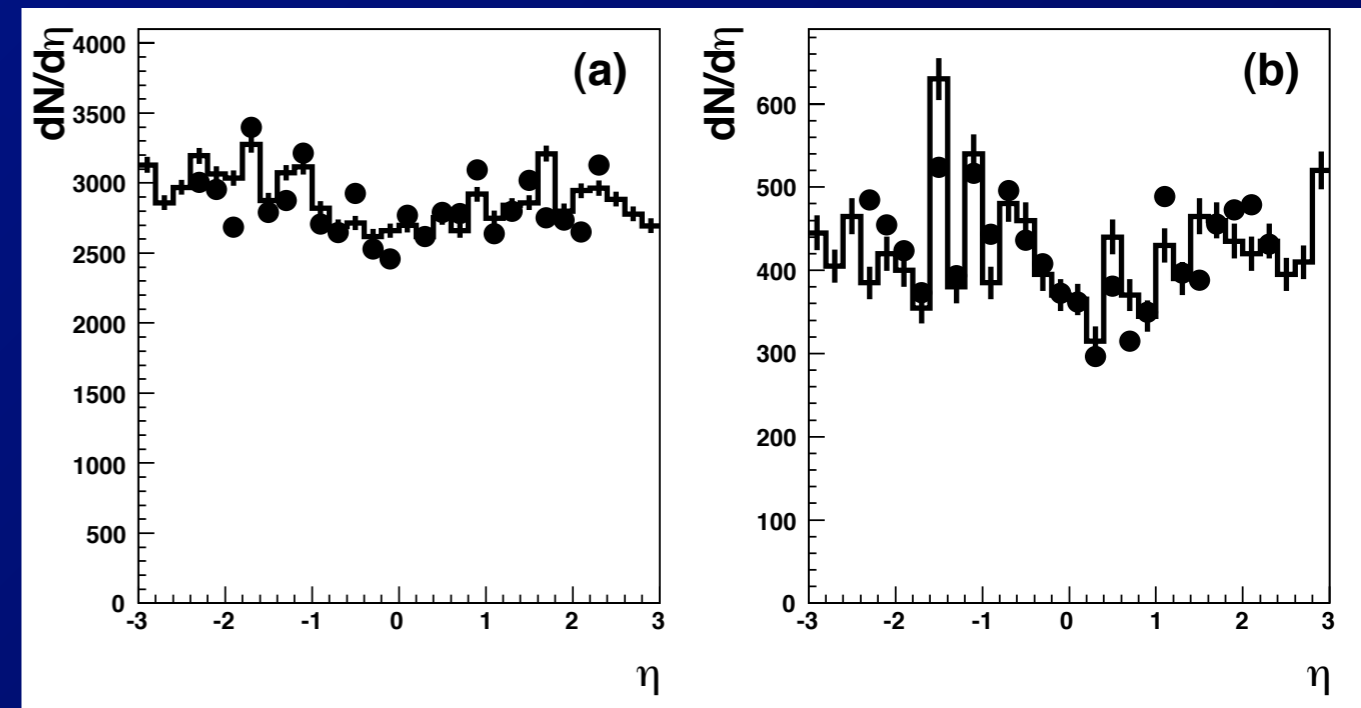
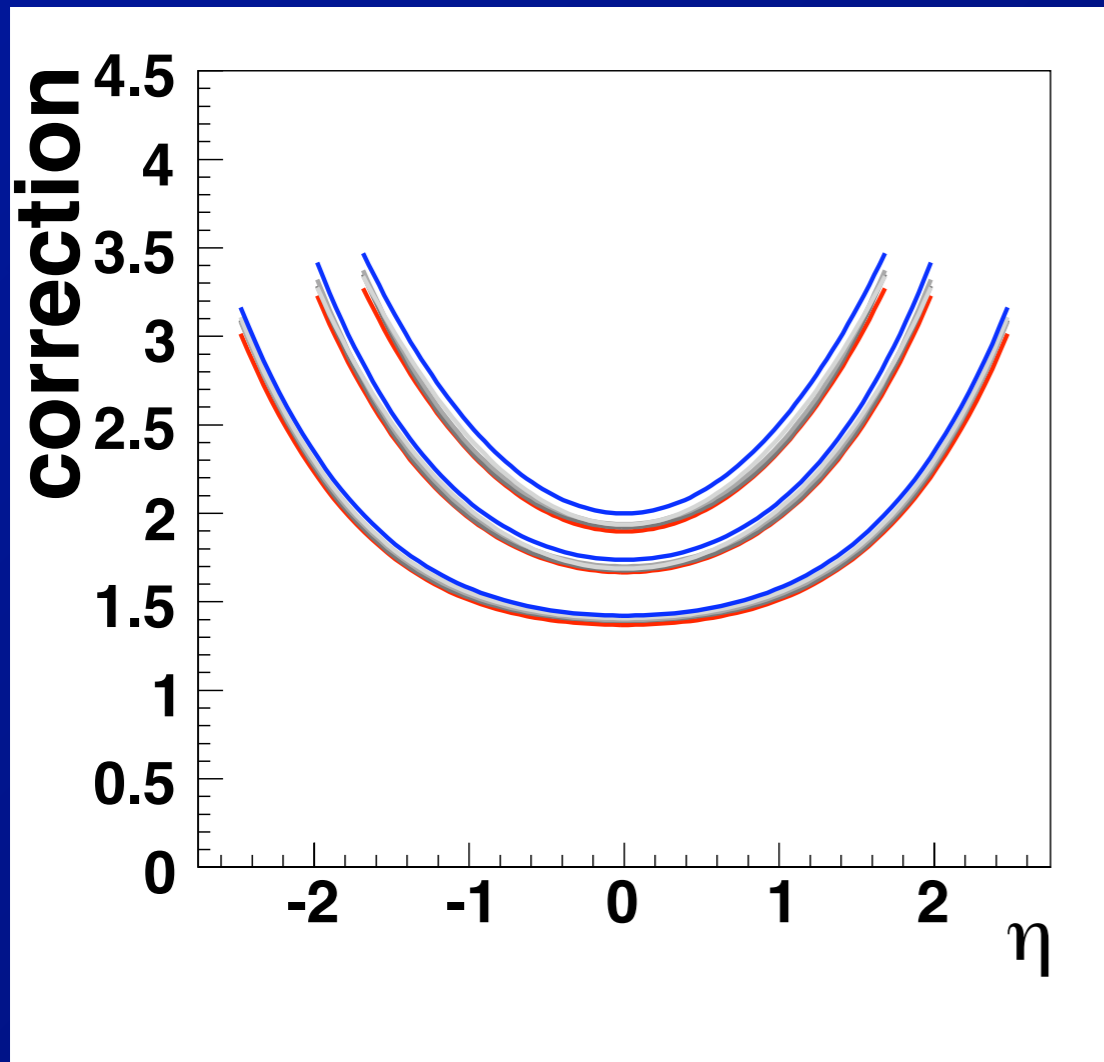
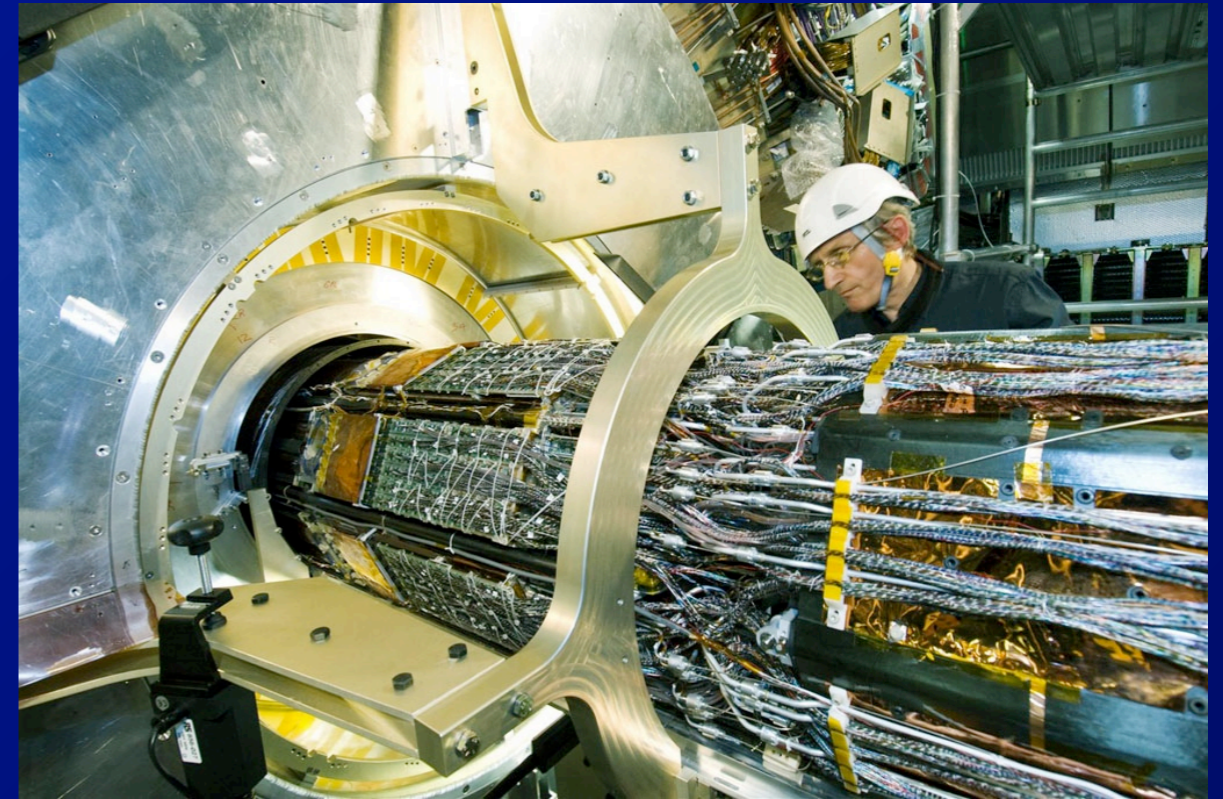
⇒ Small intrinsic fluctuations in centrality measurement.

⇒ Min-bias trigger % will dominate uncertainties.



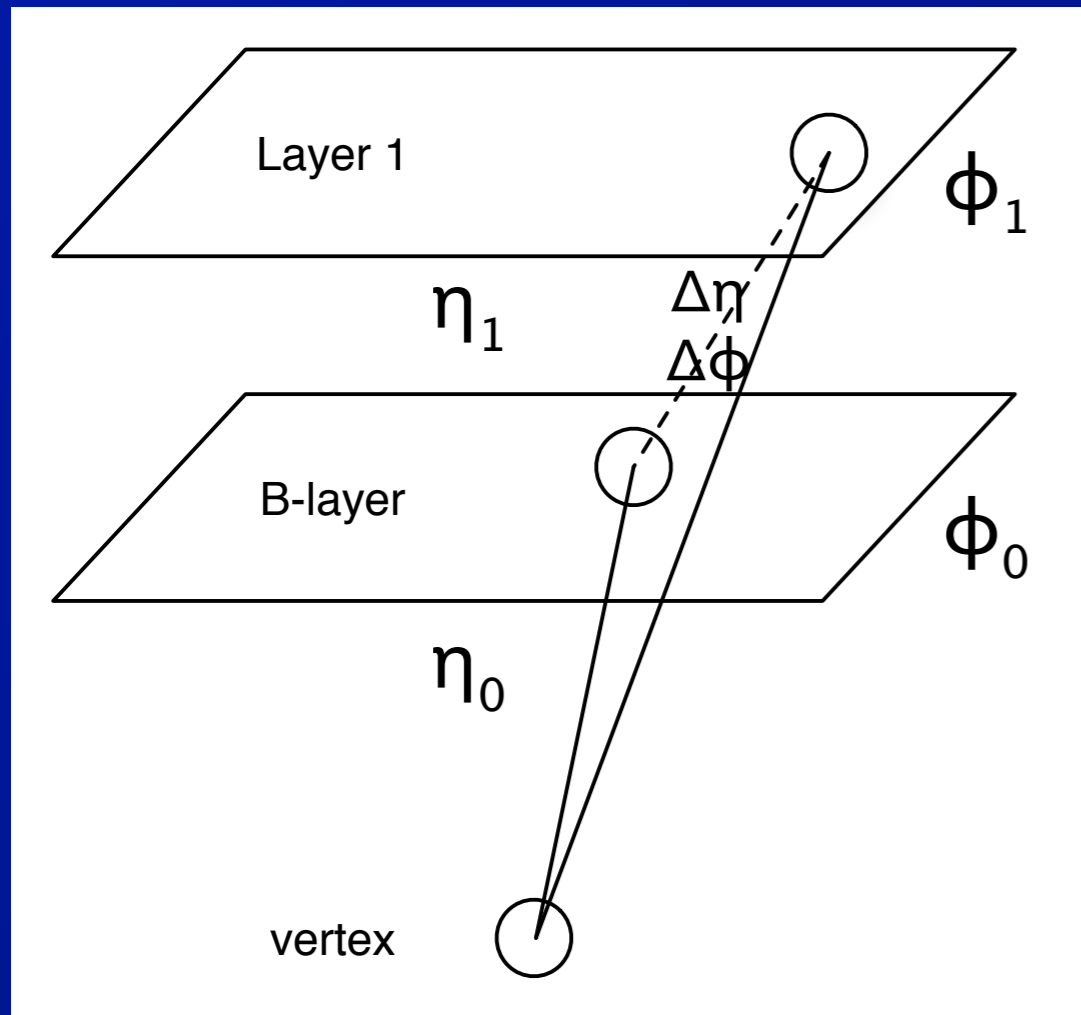
Multiplicity, $dN/d\eta$ Measurement

Pixel detector covers $|\eta| < 2.5$
Particle density can be
reconstructed event-by-event
(with η -dependent corrections)

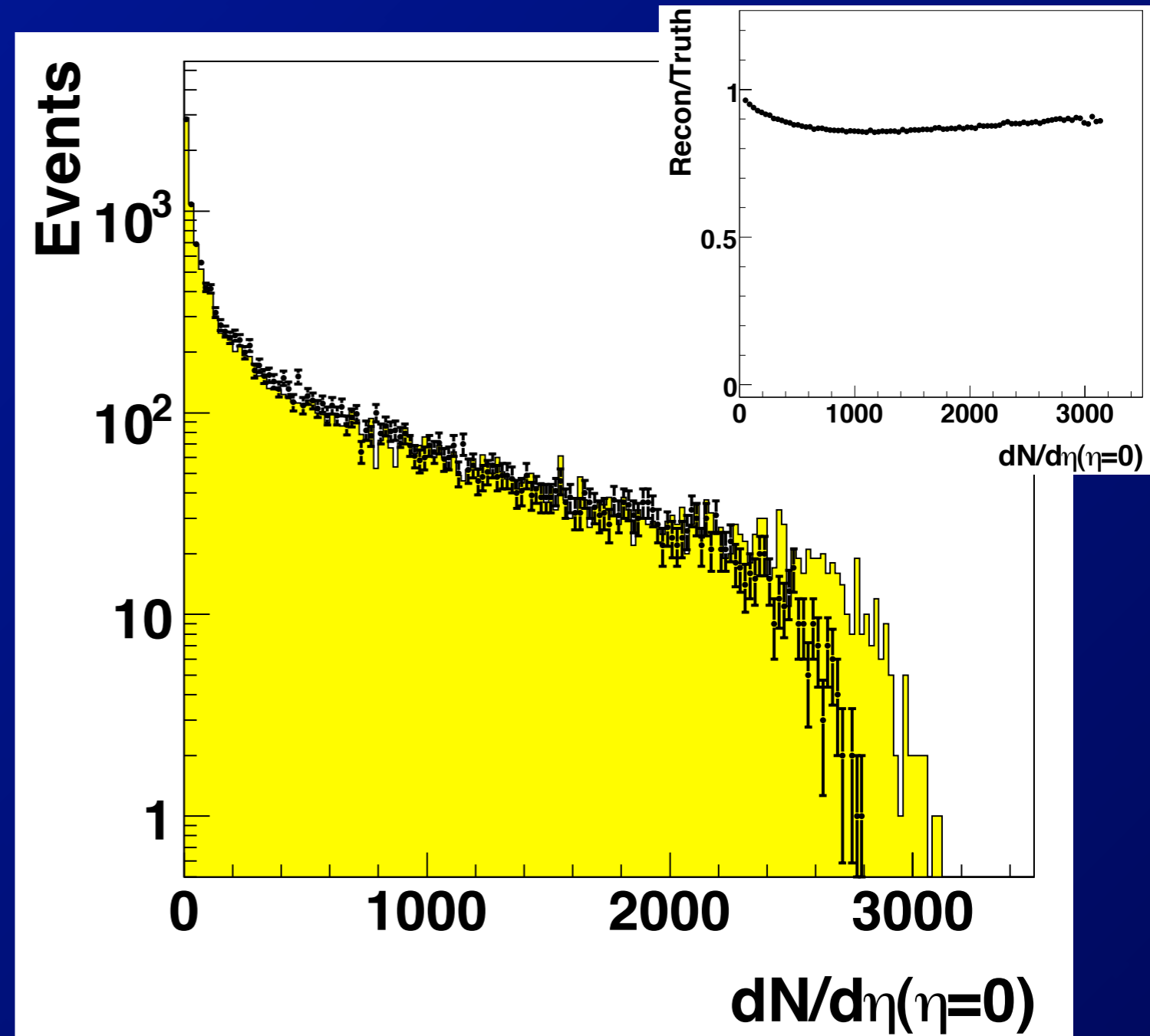


Correction from # hits/layer to charged particle multiplicity

Multiplicity, $dN/d\eta$ Measurement (2)

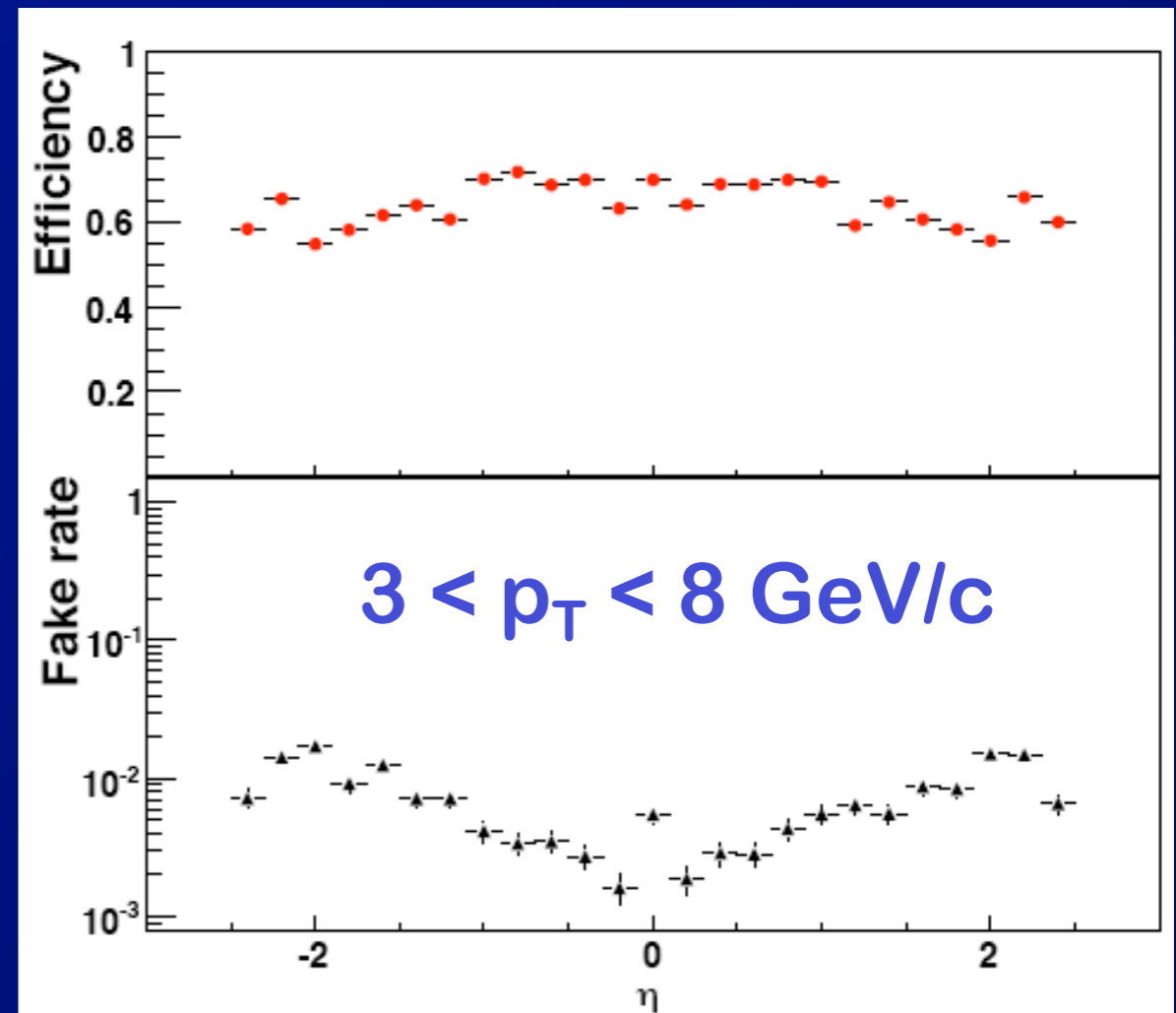
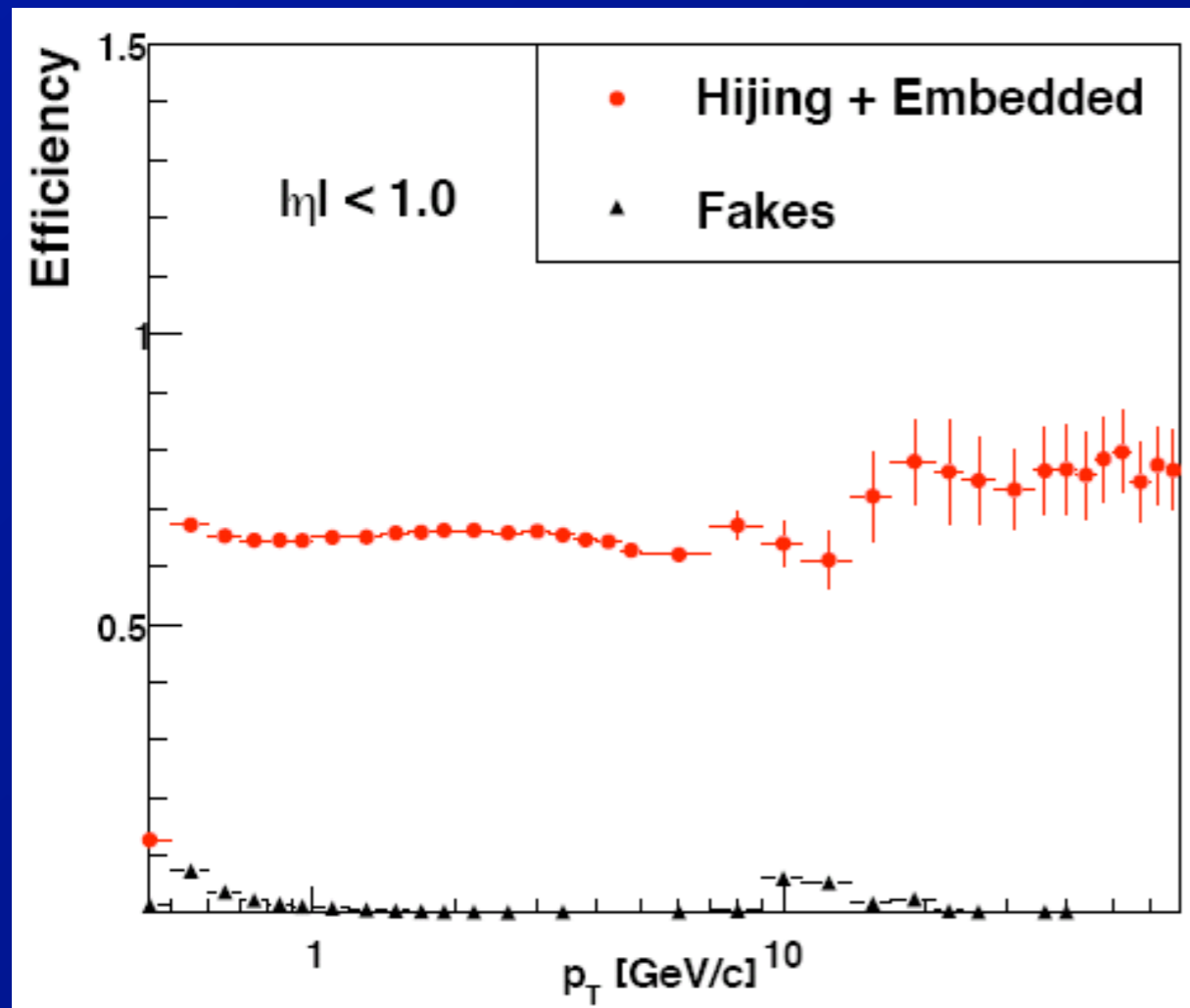


3-point tracks, including event vertex



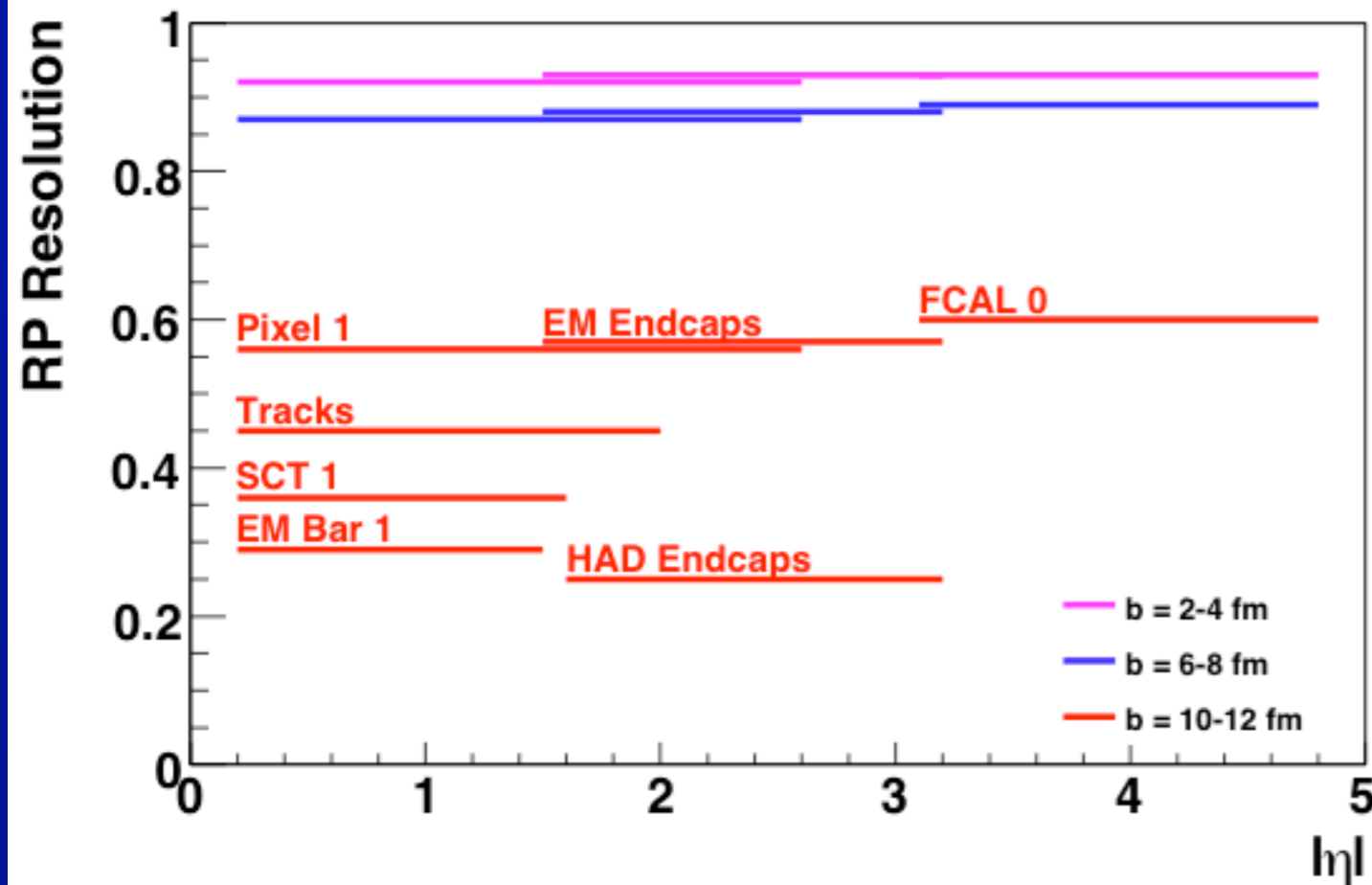
- Tracklets directly measure multiplicity, $dN/d\eta$
 - Raw distribution (points) matches HIJING min-bias (hist)
 - Maximum 15% correction over entire centrality range.

Tracking Performance



- Uniform tracking efficiency vs p_T , η
 - Crucial for controlling systematics on jet fragmentation measurements.
- Use matching to calorimeter to control fake rates at very high p_T .

ATLAS Reaction Plane Measurement



- ▶ EM Calorimeter
- ▶ Hadronic calorimeter
- ▶ Forward calorimeter
- ▶ Silicon hits
- ▶ Tracks

$$\Psi_2 = \frac{1}{2} \tan^{-1} \left(\frac{\sum w_i \sin(2\phi_i)}{\sum w_i \cos(2\phi_i)} \right)$$

$$R \equiv \sqrt{\langle \cos(2[\Psi_2^1 - \Psi_2^2]) \rangle}$$

Sub-system	η - coverage for sub-events	Resolution correction		
		$b = 10 - 12$ fm	$b = 6 - 8$ fm	$b = 2 - 4$ fm
EM Barrel Layer 1	$0.2 < \eta < 1.5$	0.29 ± 0.06	0.70 ± 0.02	0.81 ± 0.01
EM EndCaps	$1.5 < \eta < 3.2$	0.57 ± 0.03	0.88 ± 0.01	0.93 ± 0.01
HAD EndCaps	$1.6 < \eta < 3.2$	0.25 ± 0.07	0.59 ± 0.03	0.74 ± 0.02
FCAL Layer 0	$3.1 < \eta < 4.8$	0.60 ± 0.03	0.89 ± 0.01	0.93 ± 0.01
Pixel, 1st layer	$0.2 < \eta < 2.6$	0.56 ± 0.03	0.87 ± 0.01	0.92 ± 0.01
SCT, 1st layer	$0.2 < \eta < 1.6$	0.36 ± 0.05	0.71 ± 0.01	0.76 ± 0.01
Reconstructed tracks	$0.2 < \eta < 2.0$	0.45 ± 0.04	0.85 ± 0.01	0.92 ± 0.01

ATLAS v_2 measurement

- Parameterization of RHIC flow results, extrapolated:

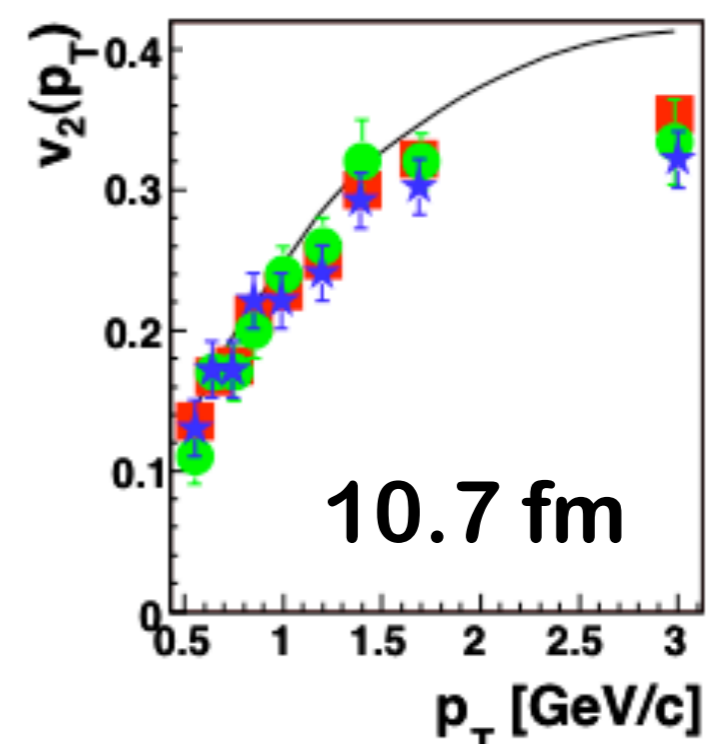
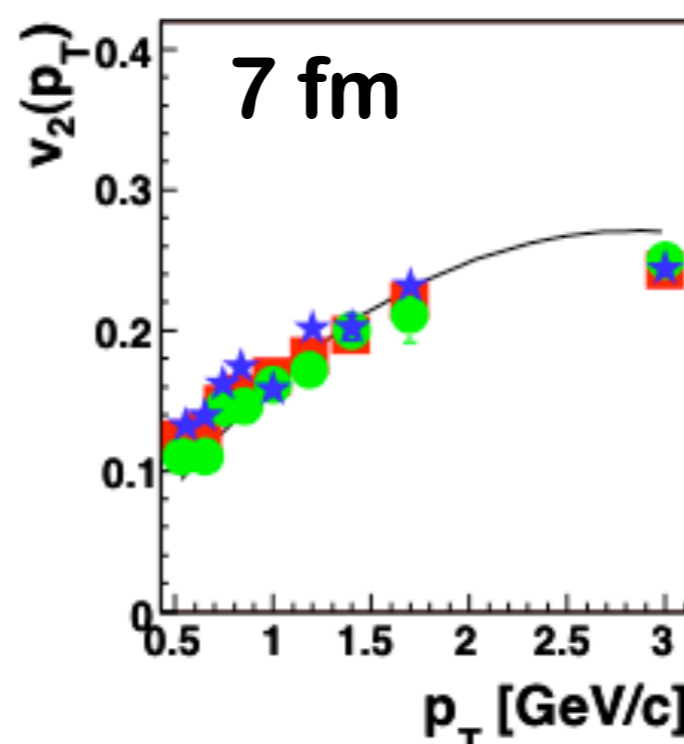
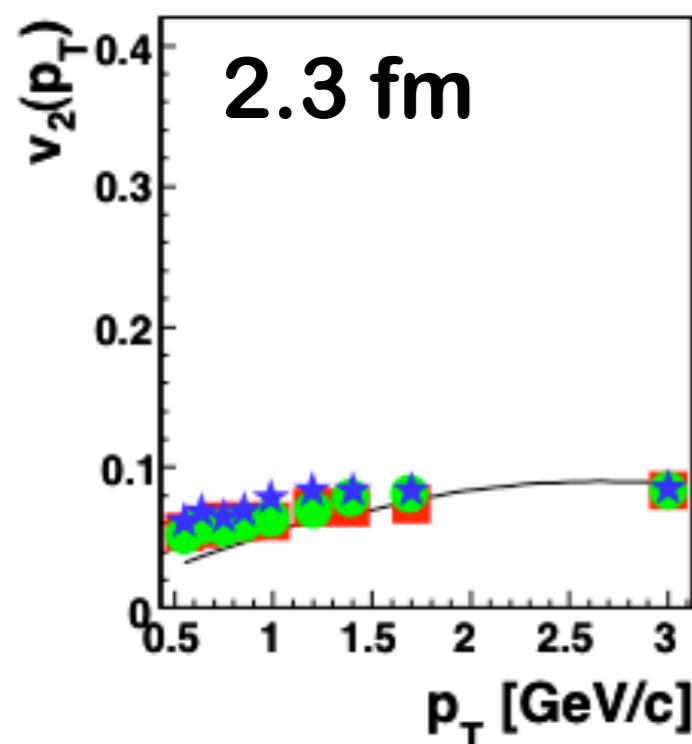
$$v_2(p_T, \eta, b) = 0.4 \times b \left[1 - \frac{2.1}{1 + e^{1.36 p_T}} \right] e^{-\frac{1}{2} \left(\frac{\eta}{6.4} \right)^2}$$

– Imposed on unquenched HIJING Pb+Pb events via φ shift

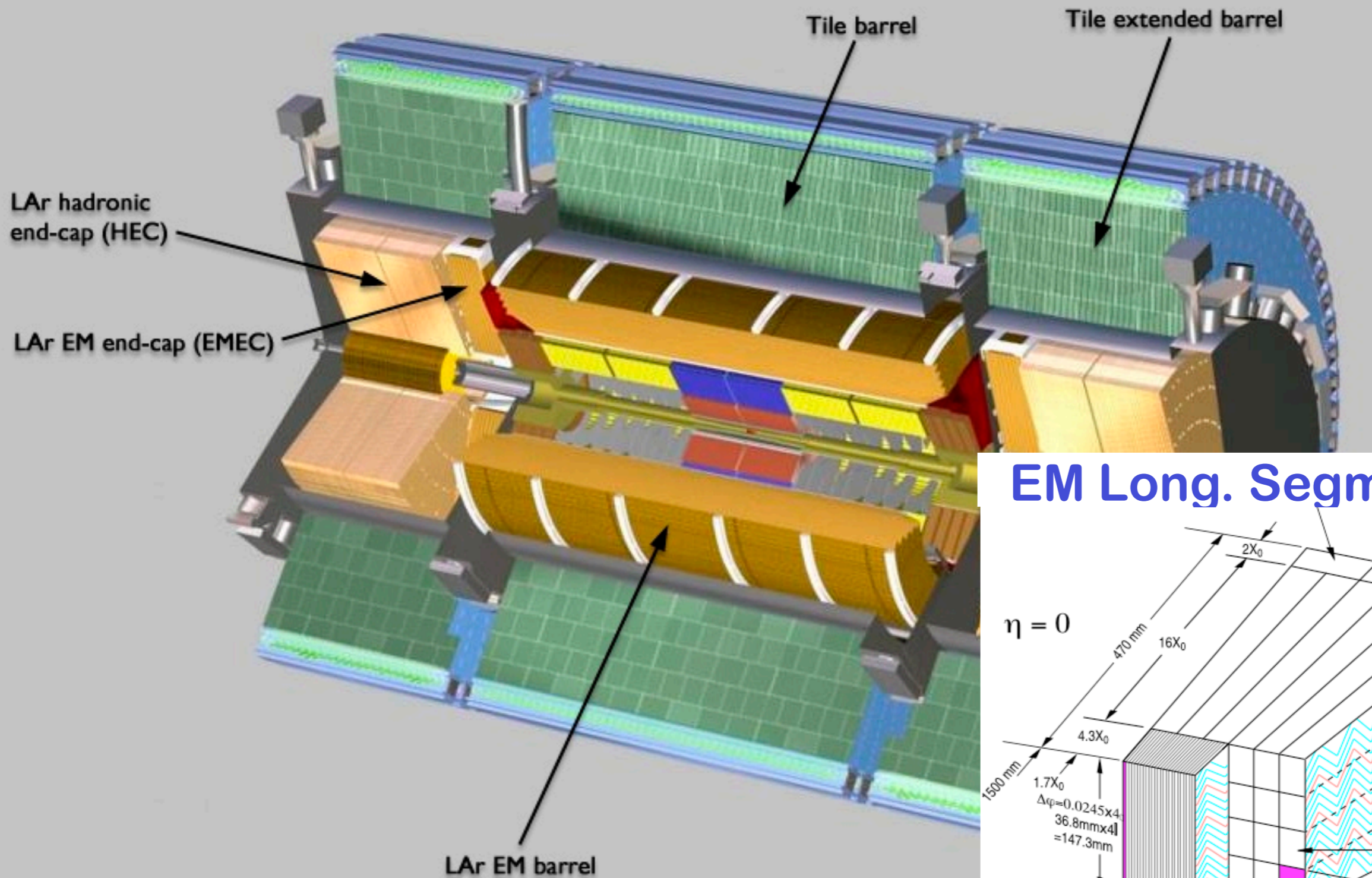
- Reconstructed charged particle v_2 vs p_T for $|\eta| < 2.5$

– Well reproduces input (except maybe central low p_T)

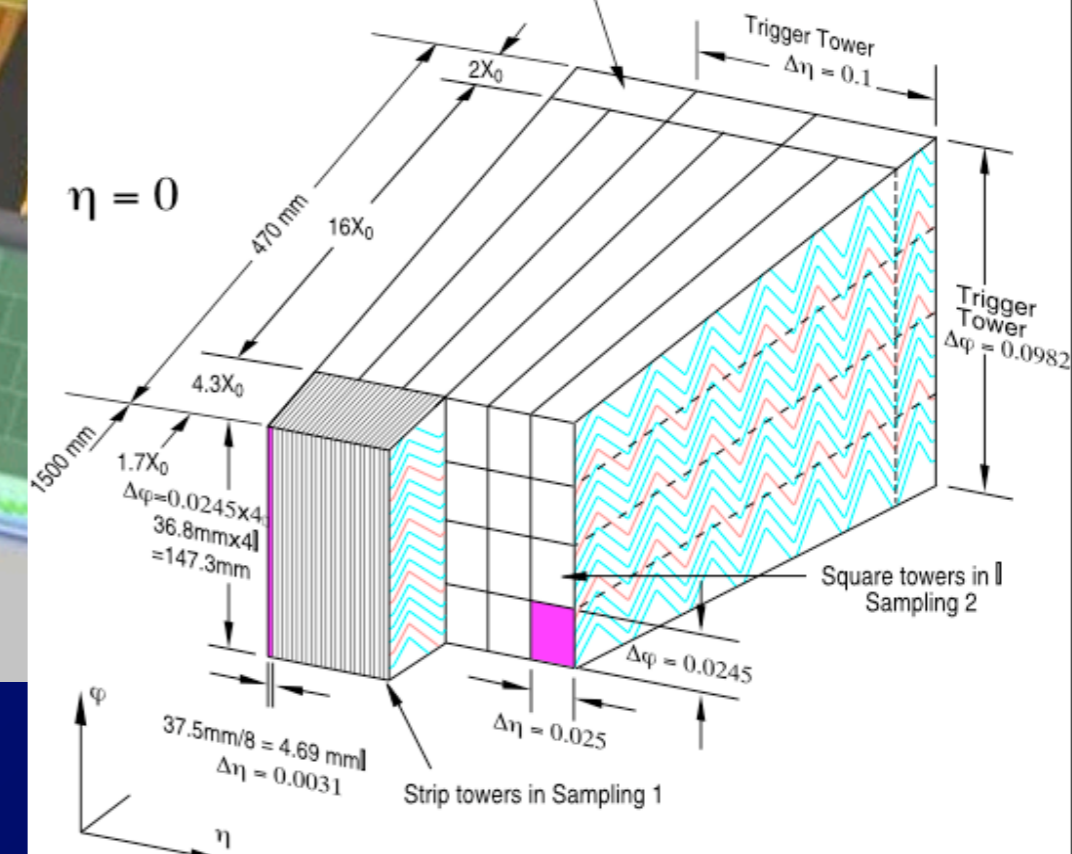
■ RP method ● Lee-Yang Zeros ★ 2-particle correlations



ATLAS Calorimetry: Long. Segmentation



EM Long. Segmentation



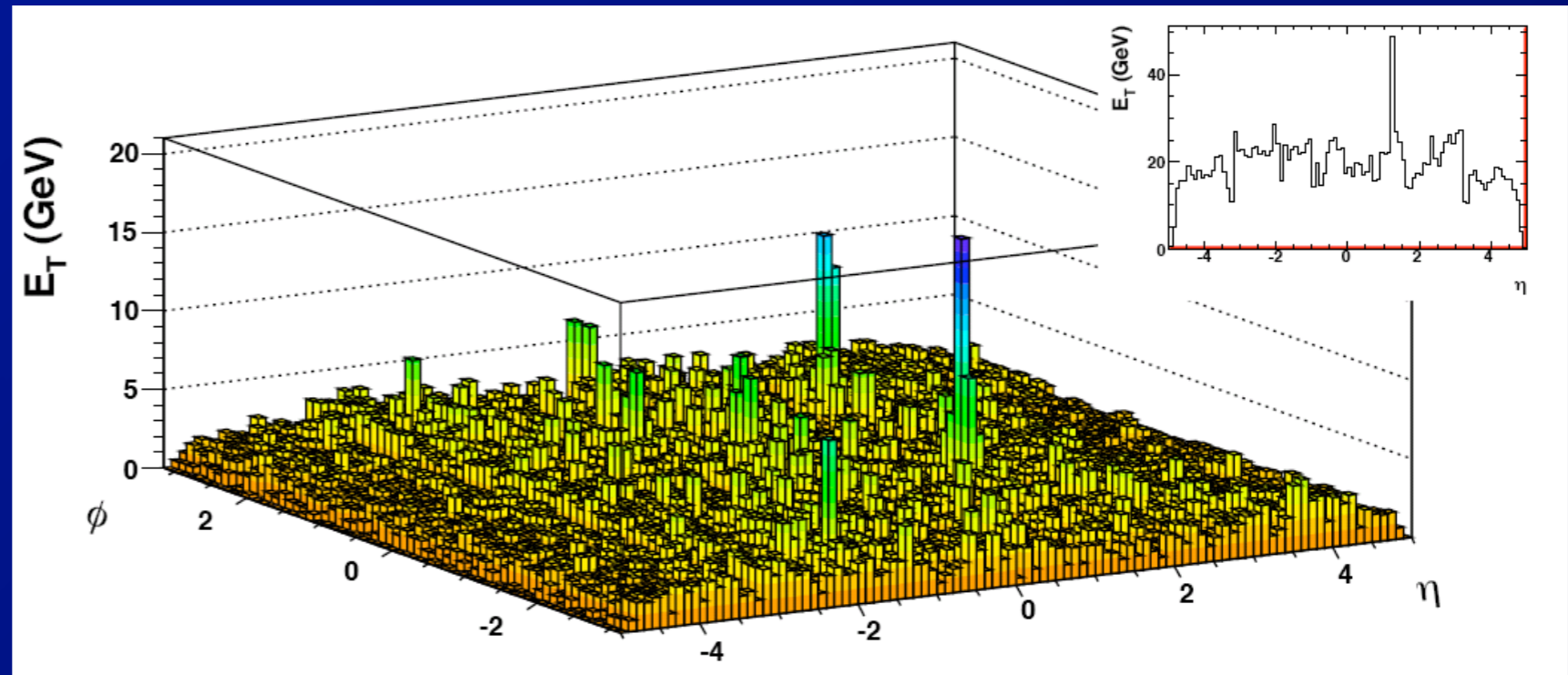
ATLAS Jet Measurements: Method

- Two jet reconstruction algorithms:
 - Iterative seeded cone algorithm, $R = 0.4$.
⇒ Run on background subtracted event.
 - Successive recombination (k_T) algorithm, $D = 0.6$.
⇒ Run on un-subtracted event (below).
- Evaluate performance w/ unmodified PYTHIA
 - Note: intrinsic variation in jet shapes, fragmentation much greater than modifications from quenching
- Embedded in HIJING Pb+Pb events
 - Without quenching
 - With full spectrum of jets, b & c production

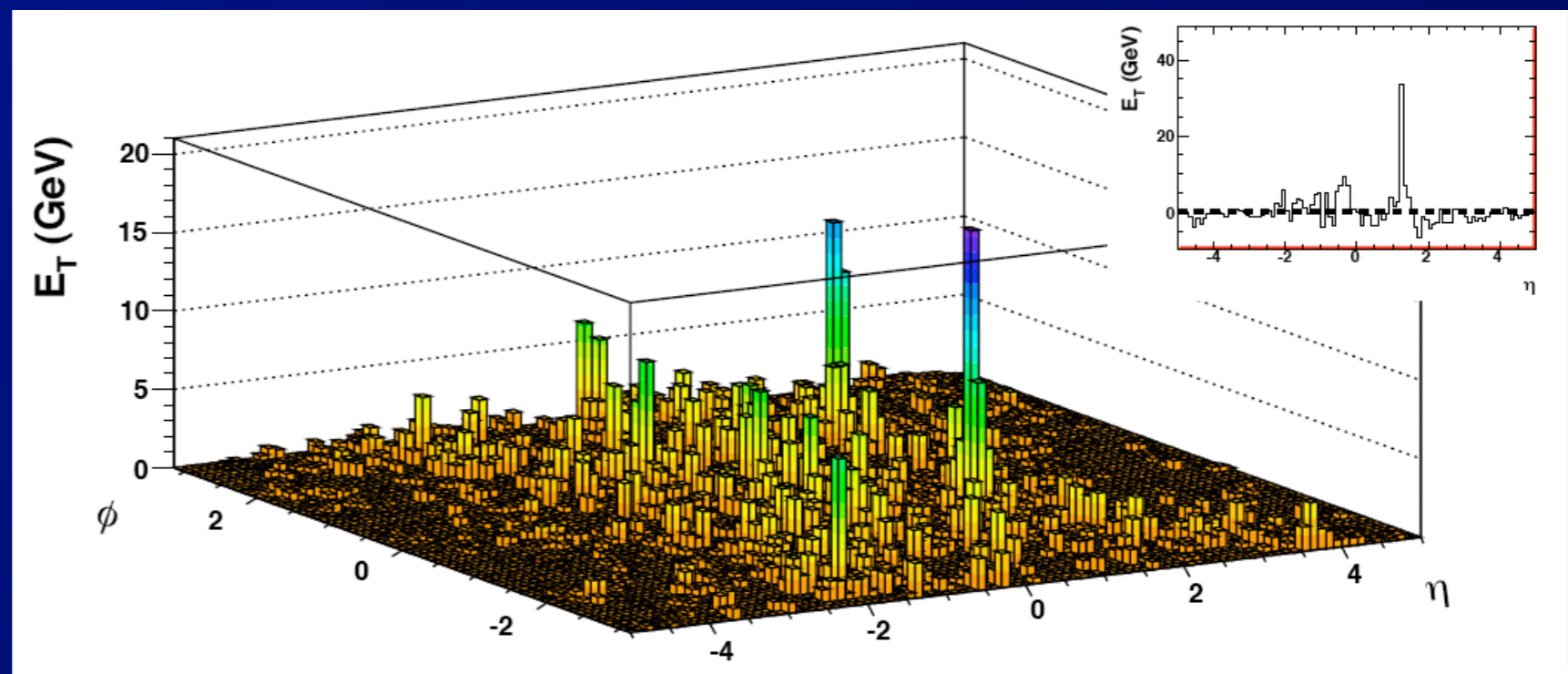
Cone Algorithm: Subtraction Example

- Pythia di-jet
 - $Q \sim 70$ GeV
- Embedded in central HIJING Pb+Pb event
 - $b = 2$ fm
 - $dN_{\text{chg}}/d\eta = 2700$
- ΣE_T in 0.1×0.1 towers
 - EM + hadronic
- Before and after bkgd subtraction.

Before subtraction



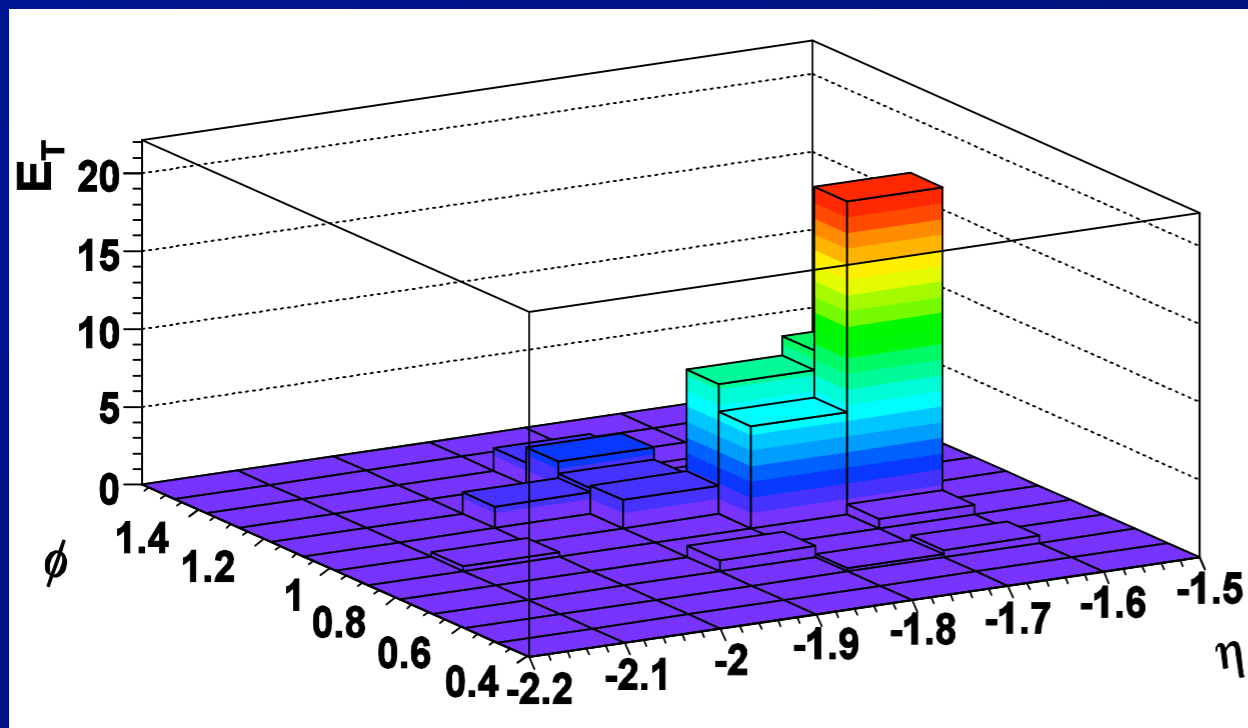
After subtraction



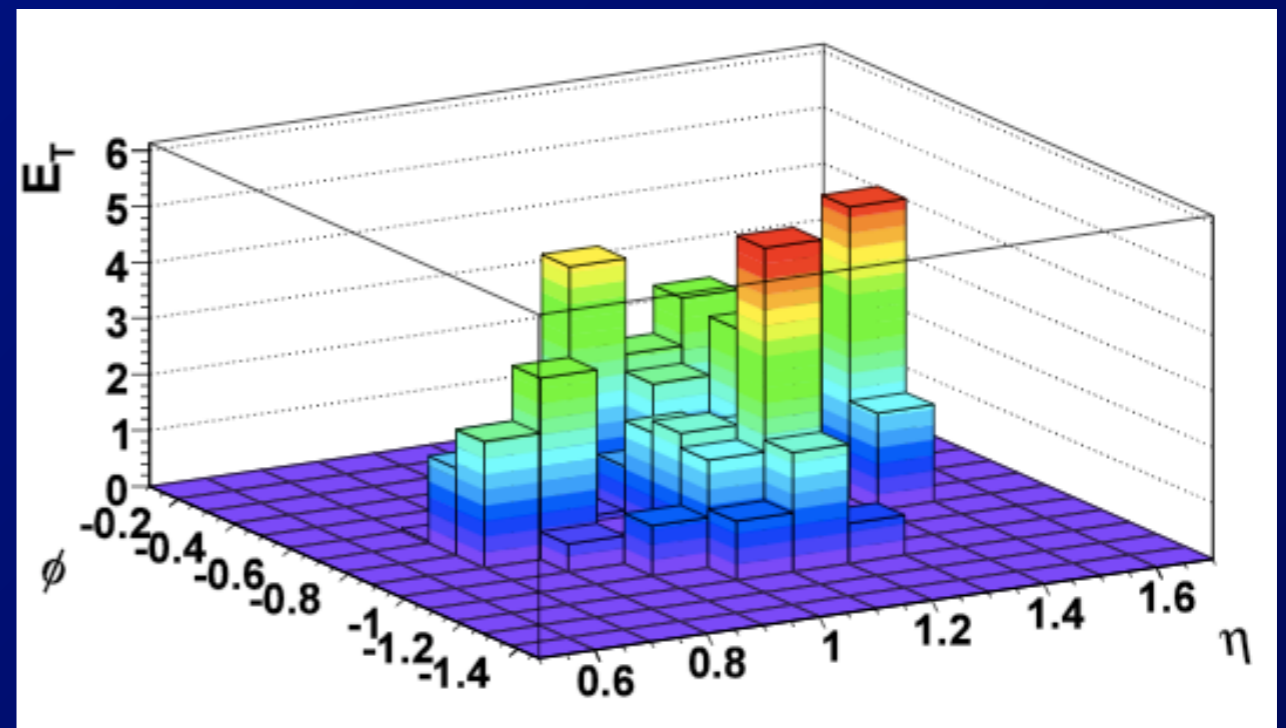
Cone Algorithm: Impact of Background

- Lesson from studies w/ HIJING background
 - Jet algorithms sensitive to correlated (semi)-hard particles in underlying event.
 - ⇒ mini-jets, b-bbar, c-cbar, high mass resonances
 - Fluctuations in soft background less important.
 - Particular issue for cone algorithms.

Real jet (atypical)



Fake jet from background

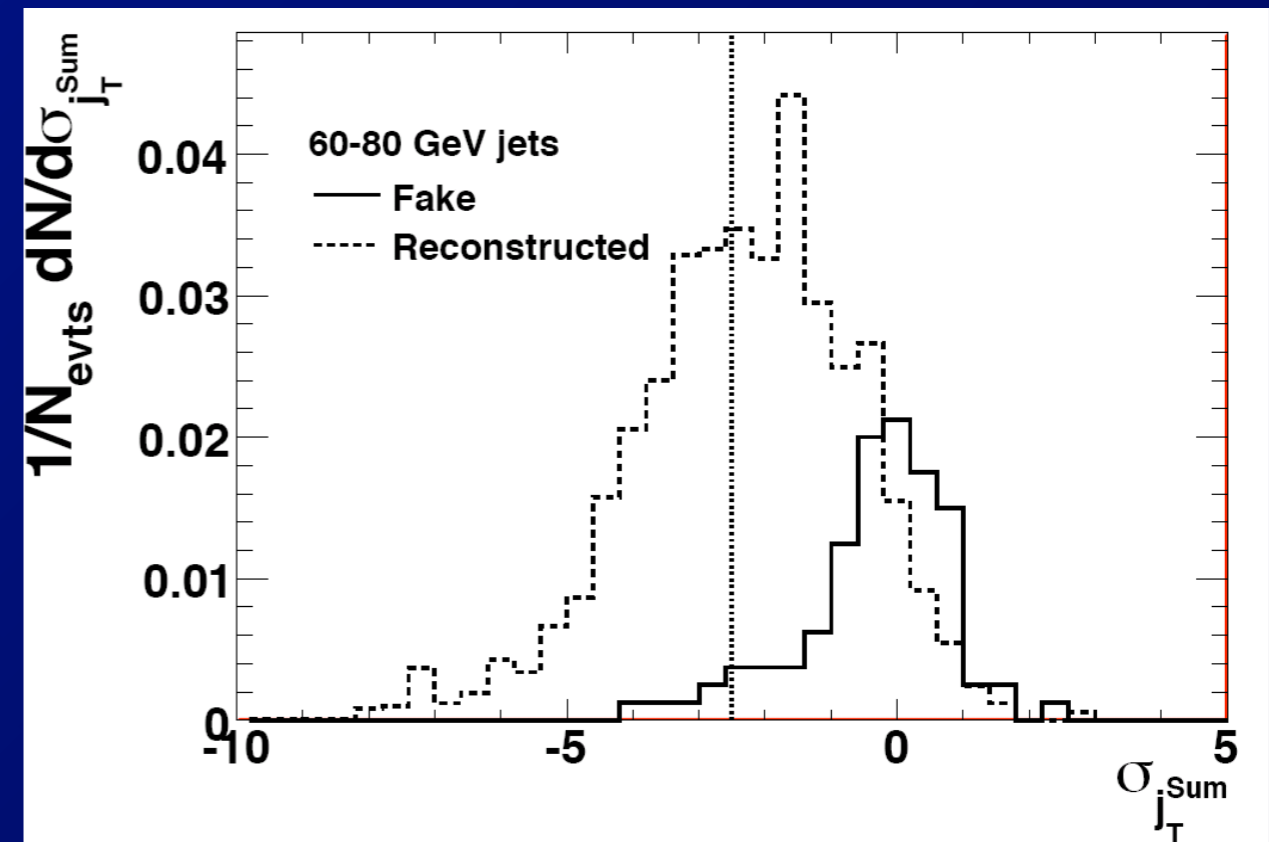
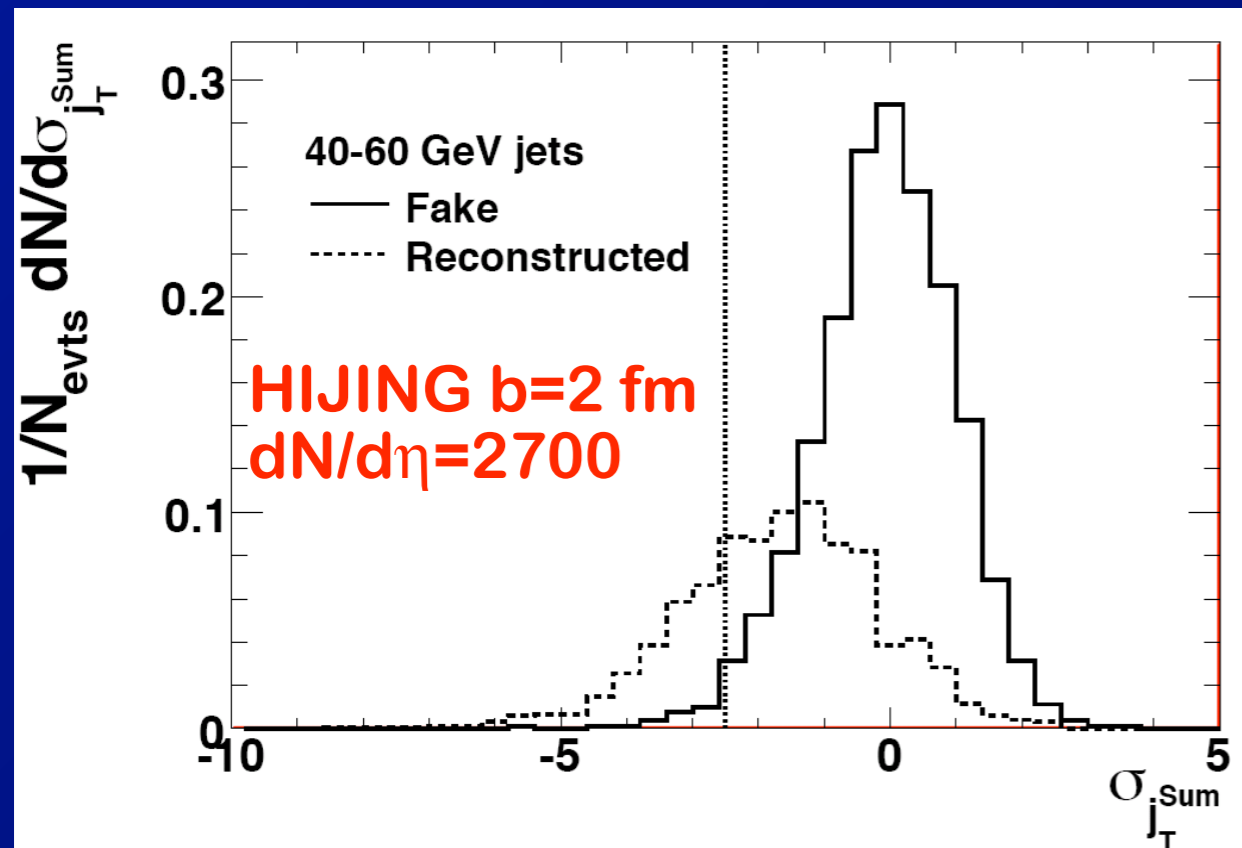


Cone algorithm: Background Rejection

- Reject background based on jet “shape”
- Best quantity that we have found: ΣJ_T

$$\Sigma J_T \equiv \sum_{\text{towers}} E_T \sin R$$

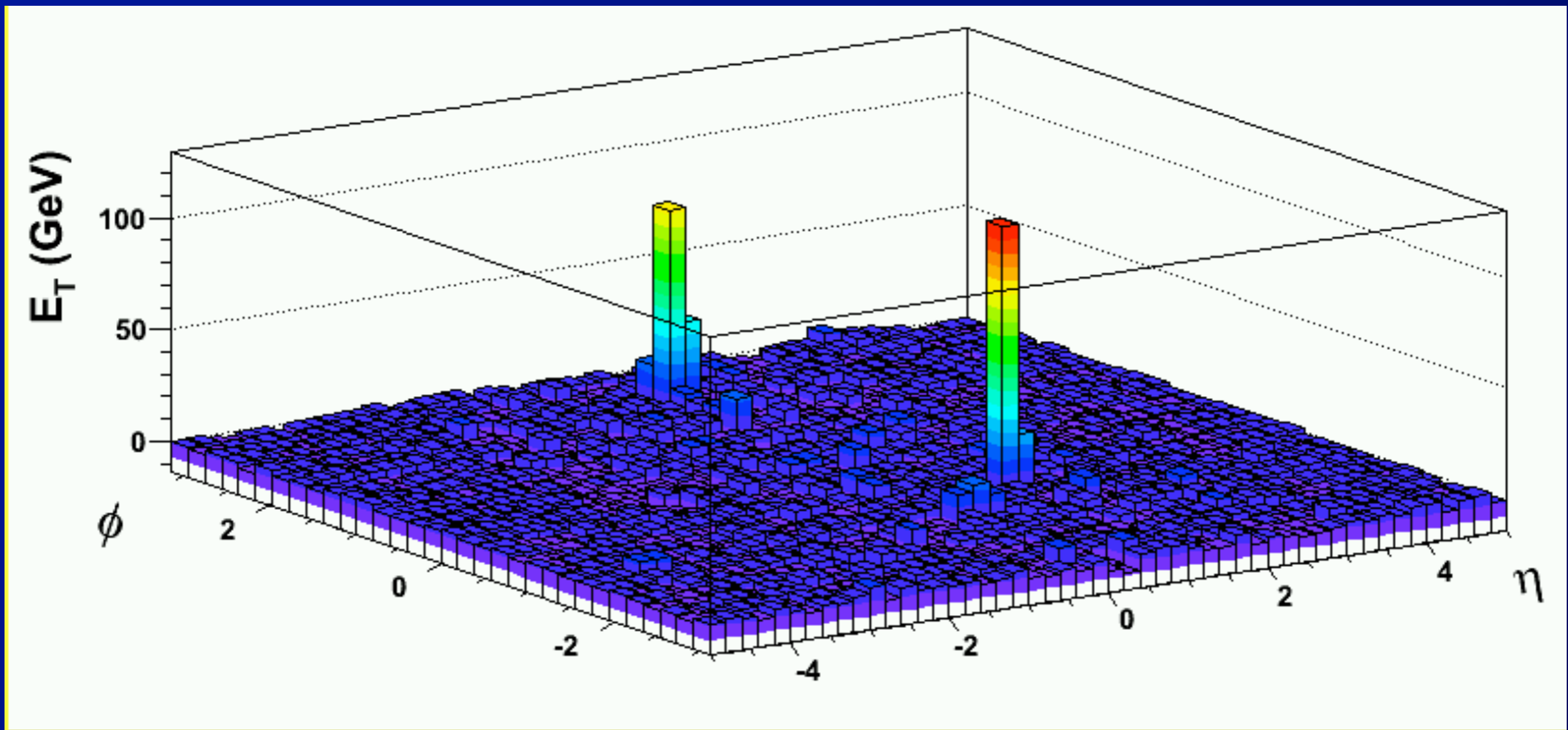
- Sensitive to energy on jet periphery
 - Less sensitive to (changes in) energy at jet center.



Discriminator: # of σ 's separated from fake jet mean ΣJ_T

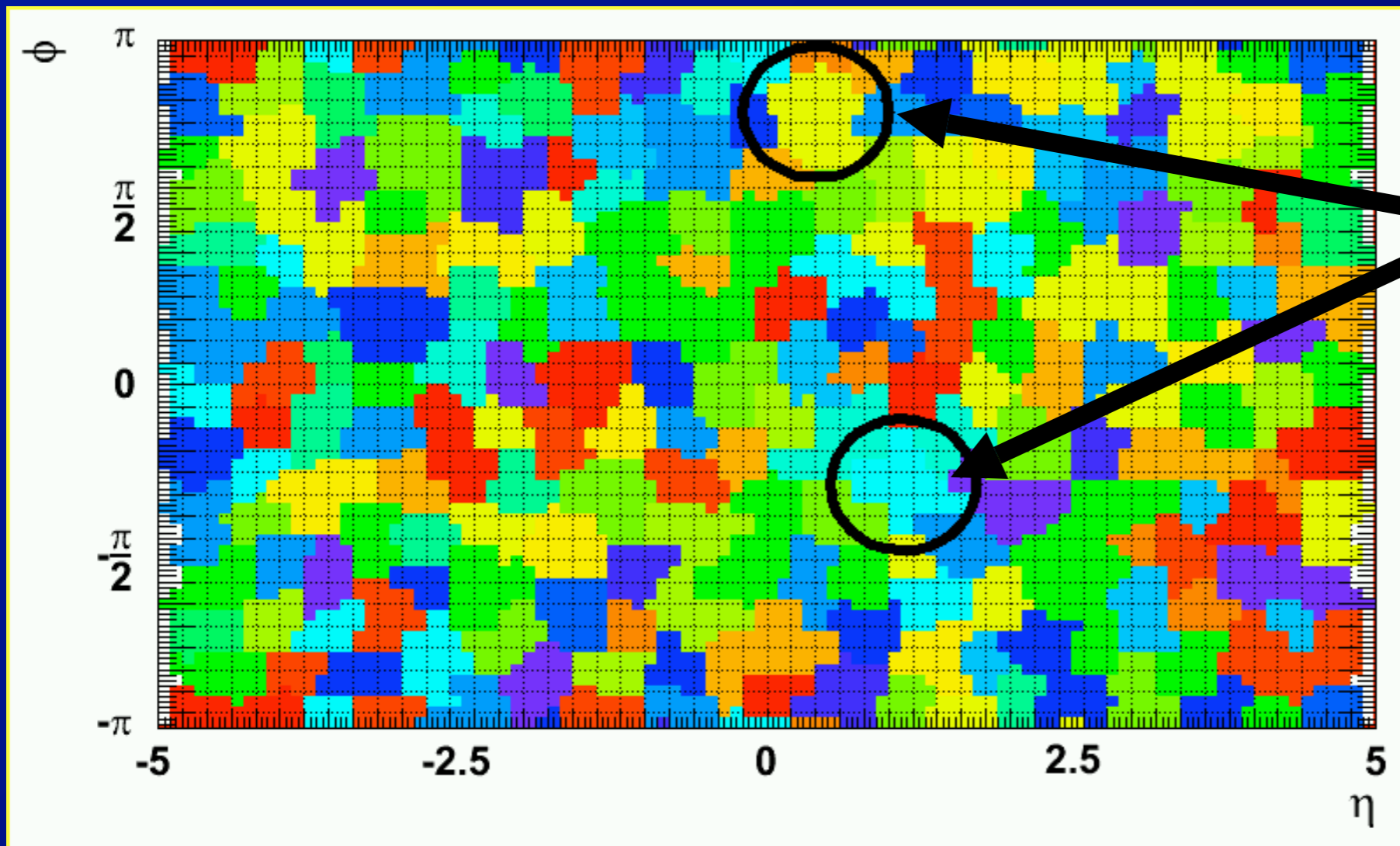
ATLAS: K_T Algorithm

- Use method suggested by Cacciari, Salam
 - Start with un-subtracted event



ATLAS: K_T Algorithm

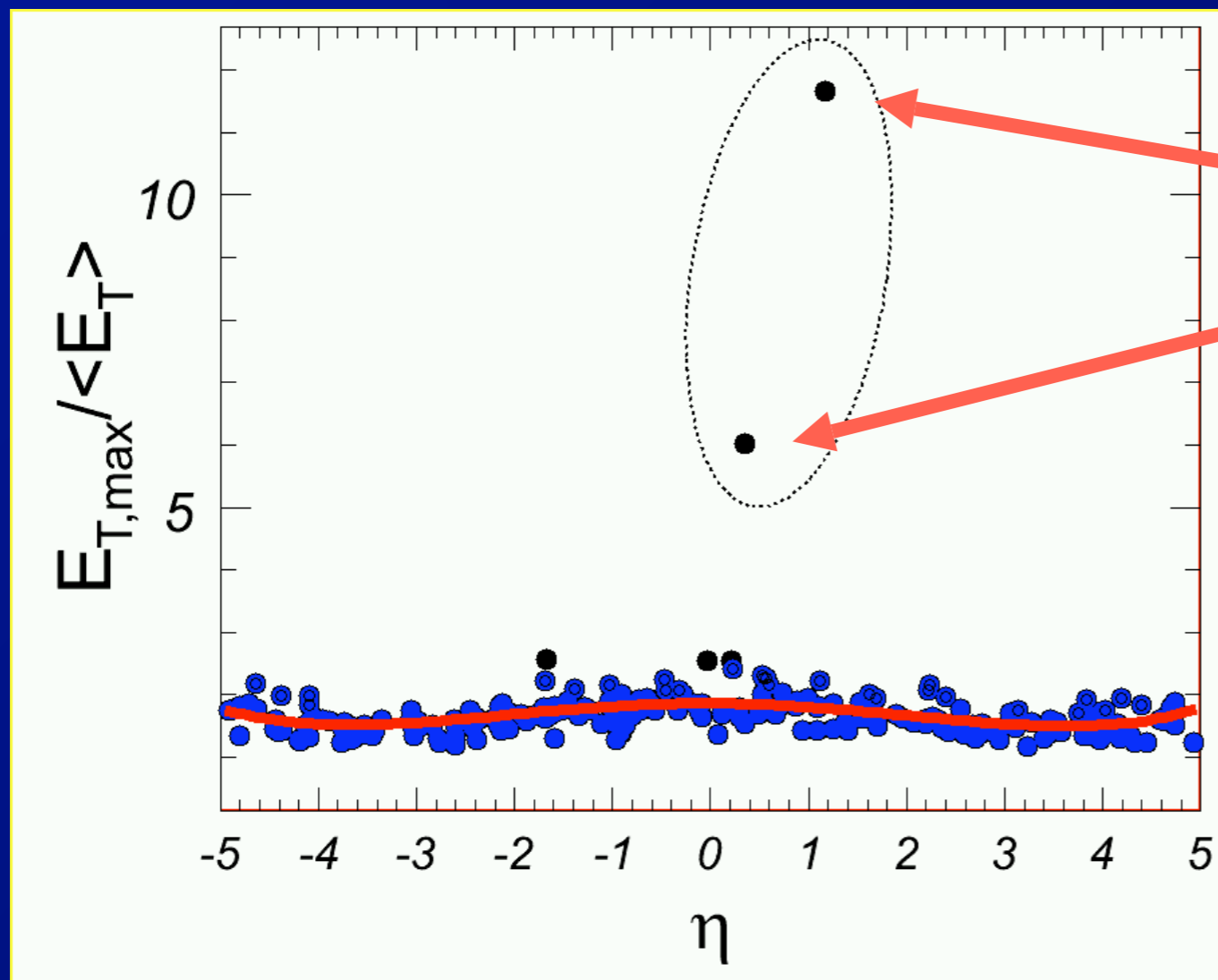
- Use method suggested by Cacciari, Salam
 - Start with un-subtracted event
 - Apply K_T algorithm using Fast implementation.



Embedded
PYTHIA
di-jets

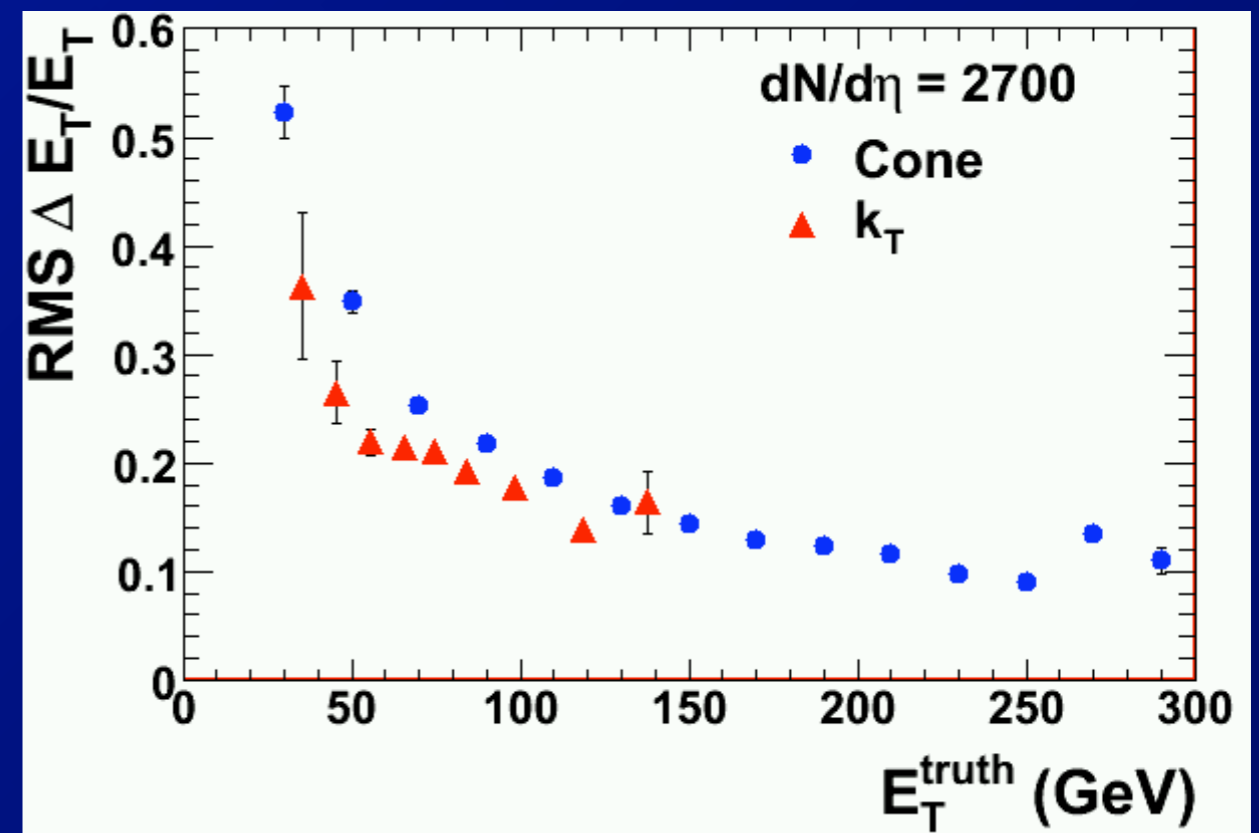
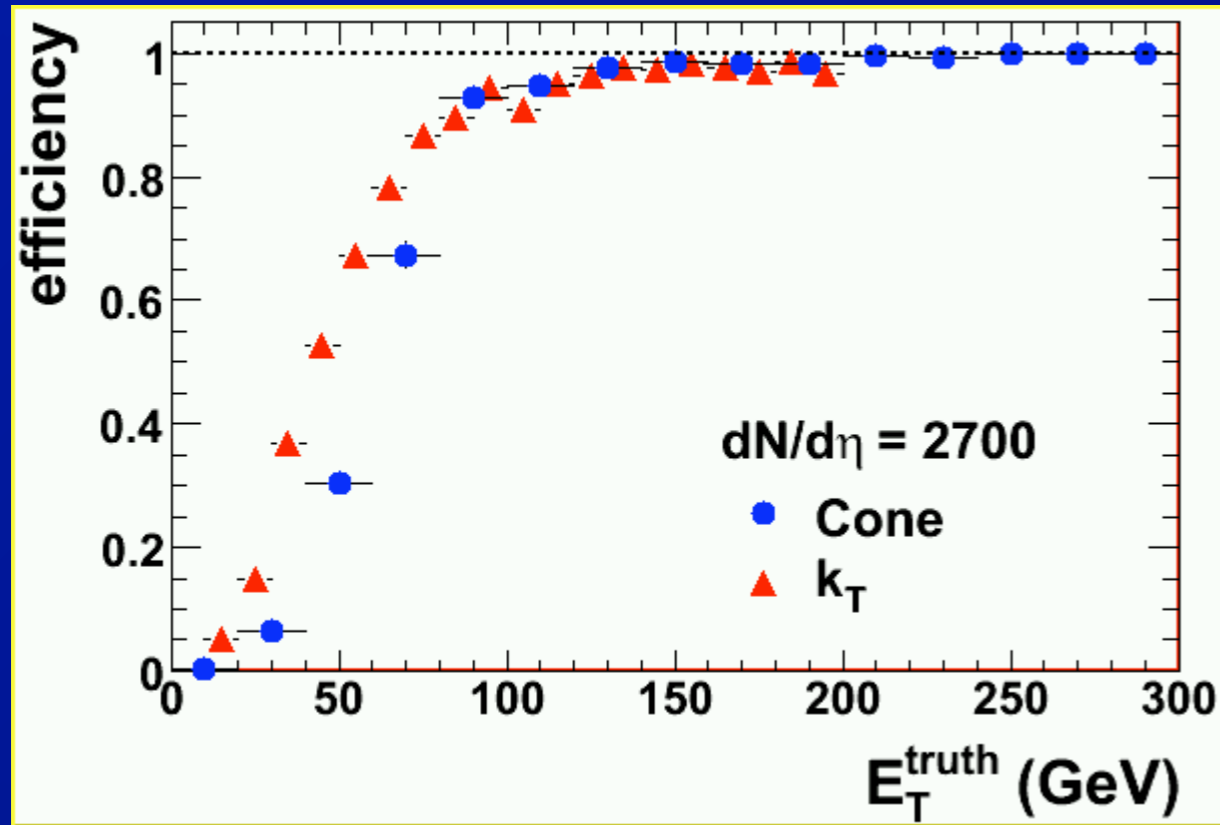
ATLAS: K_T Algorithm

- Use method suggested by Cacciari, Salam
 - Start with un-subtracted event
 - Apply k_T algorithm using Fast implementation.
 - Discriminate between real & false jets.
- ⇒ Use to measure background -- subtract from real.



Embedded
PYTHIA
di-jets

ATLAS Cone vs k_T Algorithm



- Observe better performance for k_T algorithm

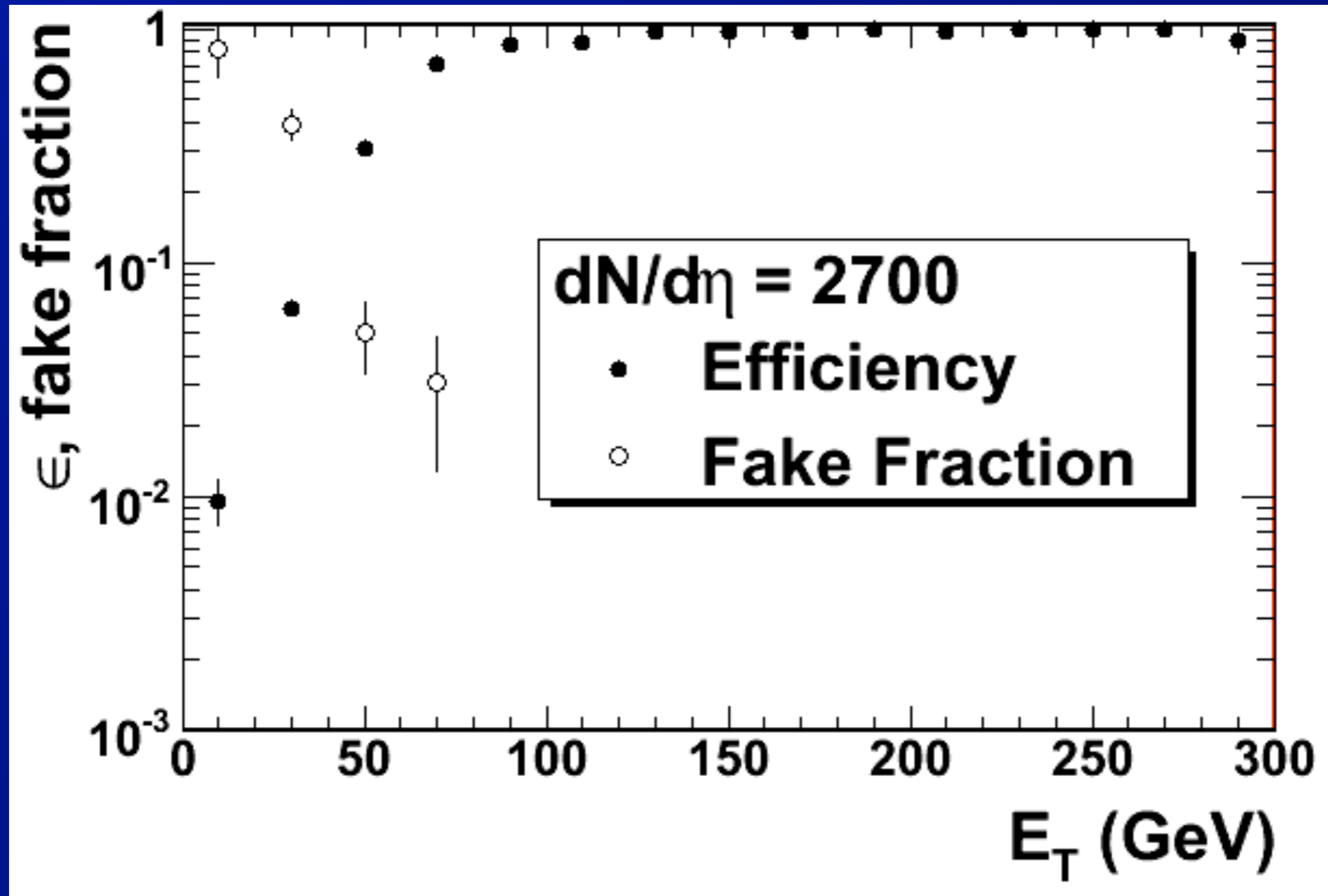
- Better efficiency and energy resolution
- Due to intrinsic properties of algorithm

- But \exists problem with k_T algorithm too

- Centrality dependent, systematic shift in energy scale
- Due to absorption of towers @ jet edge into bkgd.

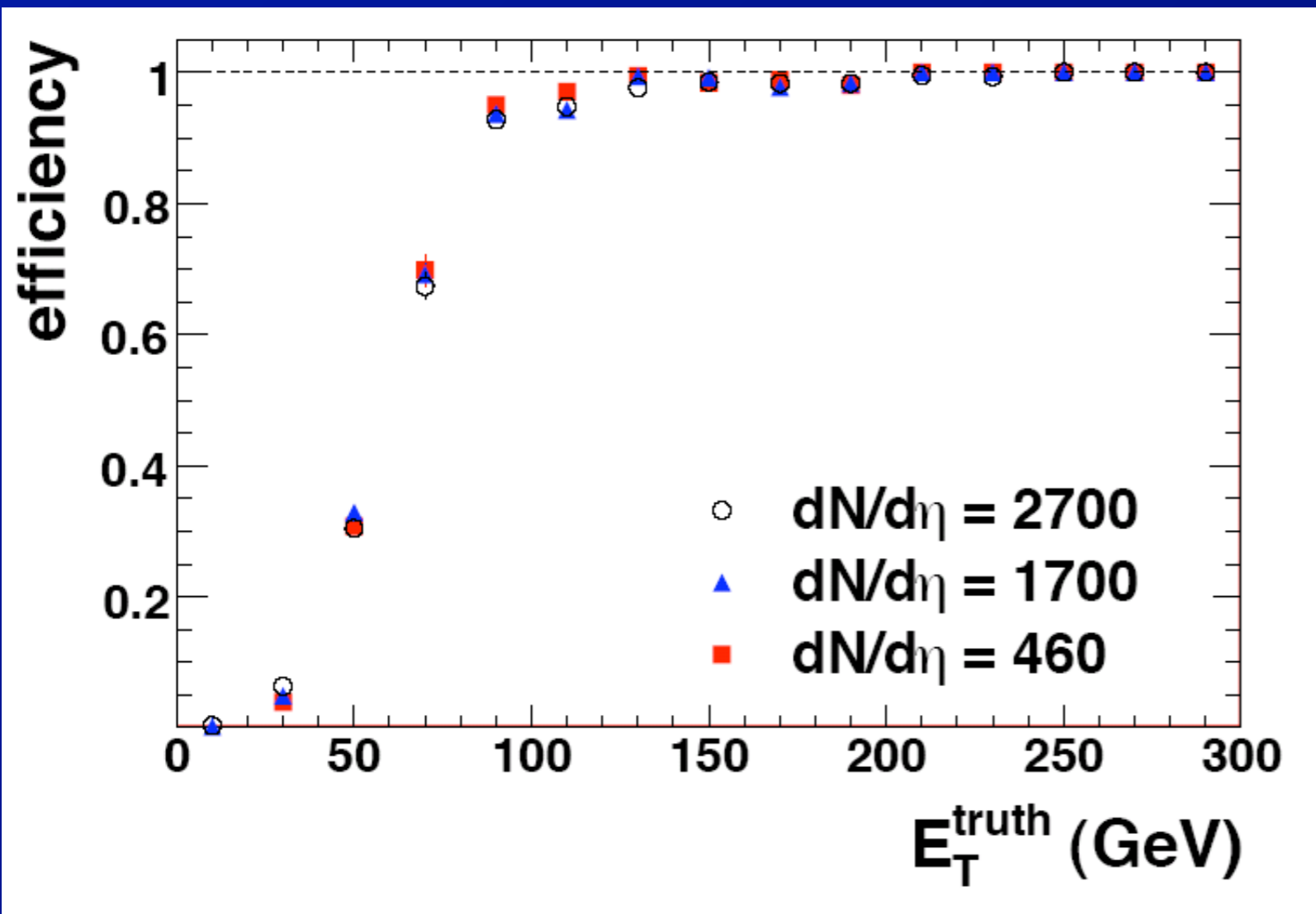
⇒ Focus on cone algorithm results for rest of talk

Cone Jet Algorithm: Efficiency & Fake Rate



- Includes 2.5σ discrimination against fake jets
 - 70% efficiency, 3% fake rate @ 70 GeV
 - In worst-case HIJING background.

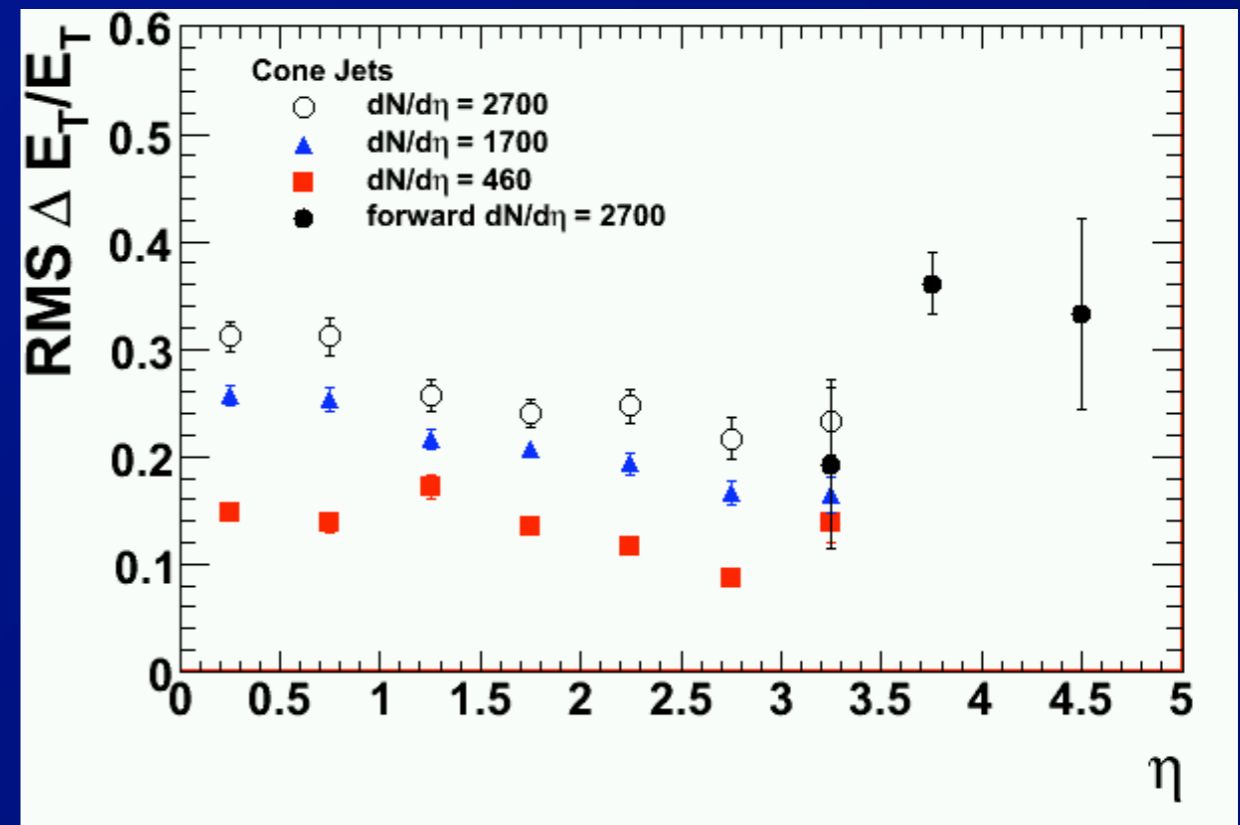
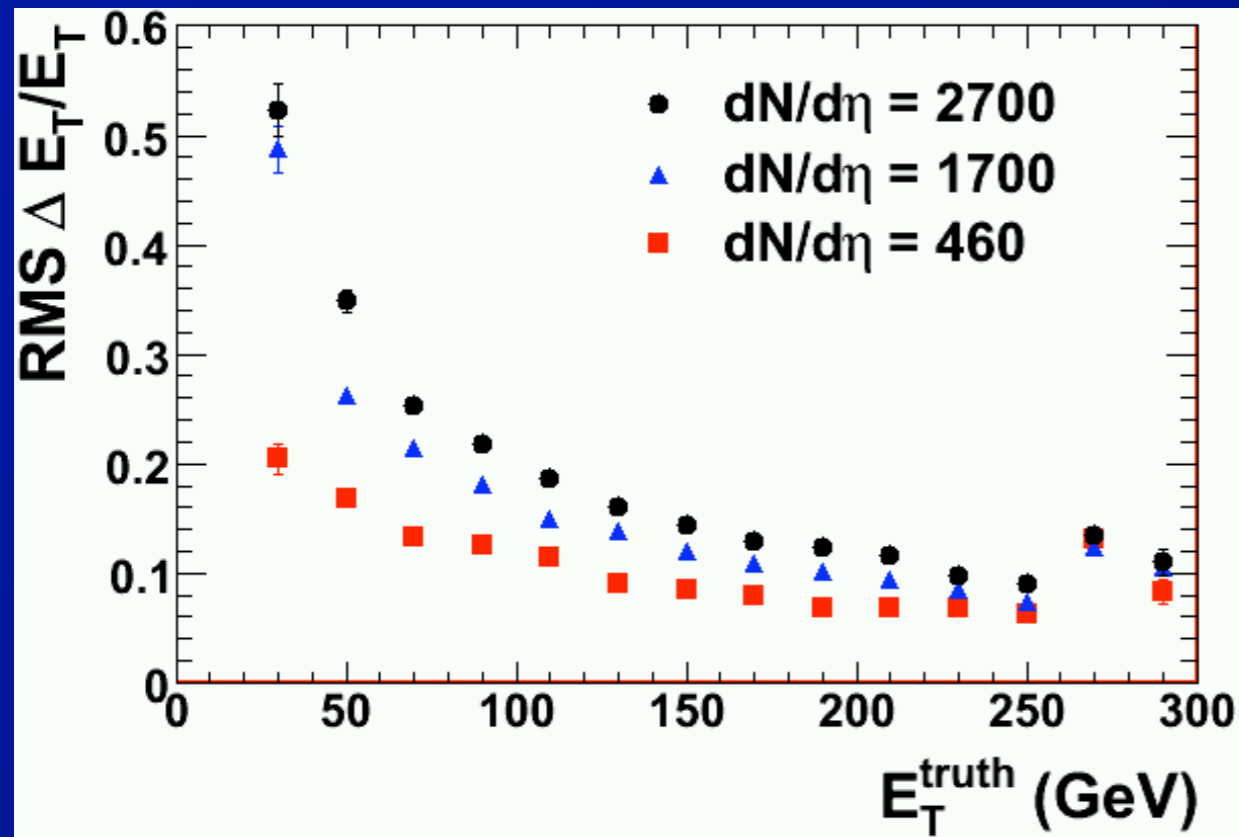
Efficiency vs. Centrality



Efficiency includes cone algorithm with

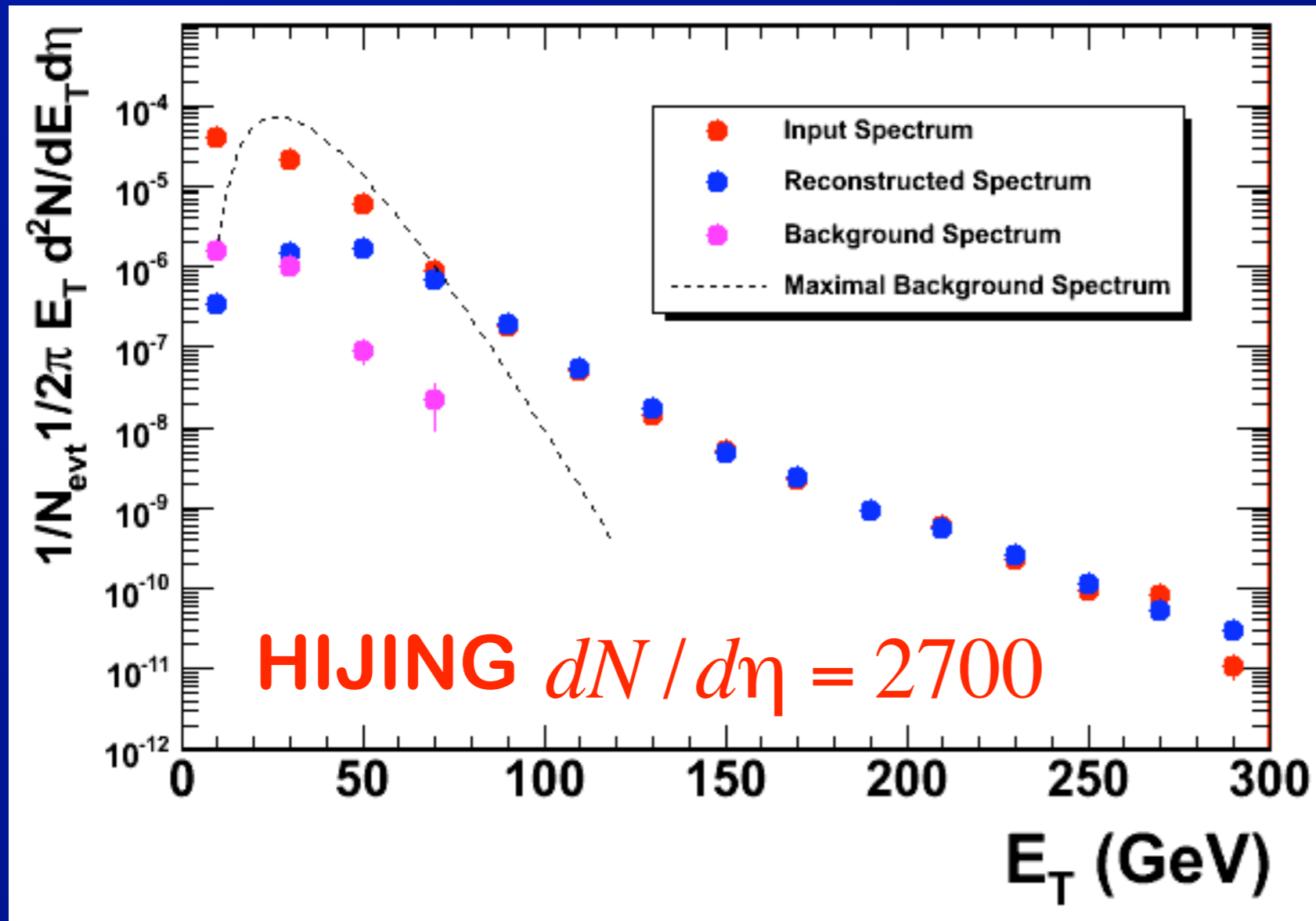
- Same (tight) background rejection cuts for all centralities – not necessary but advantageous
 - Biases from bkgd rejection centrality independent
- Efficiency independent of centrality
 - ⇒ Crucial for understanding quenching effects

Cone Jet Energy Resolution



- Fractional energy resolution using $\text{RMS } \Delta E_T / E_T$
 - Smooth Evolution with centrality
 - Slightly worse resolution near $\eta = 0$
 - \Rightarrow Most sensitive to HIJING (semi)-hard particles
- Worse resolution at large η due to forward calorimeter segmentation – but jets still measurable out to $|\eta| = 5$.
- (artifact at $E_T \sim 280$ due to PYTHIA sampling)

Jet Spectrum

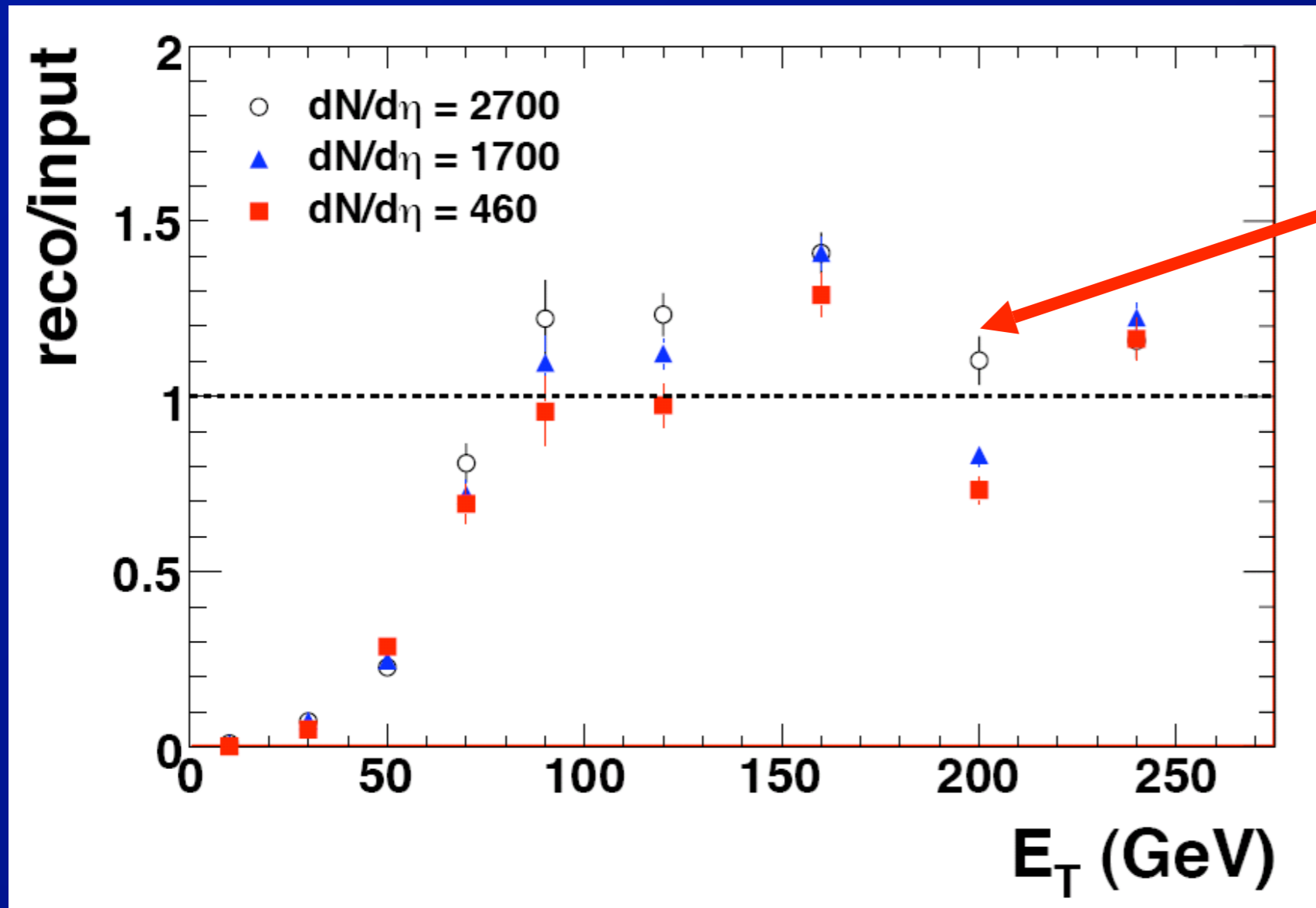


For 70 GeV jets in
 $b=2$ fm HIJING
($dN/d\eta = 2700$)

- $\varepsilon = 70\%$
- $B/(S+B) = 3\%$
- $\sigma(\Delta E_T/E_T) = 25\%$

- Including tight background rejection cuts, all experimental effects, $|\eta| < 5$
 - Good reproduction of jet spectrum above 70 GeV
 - For “worst-case” background (?).

Jet Spectrum (2)

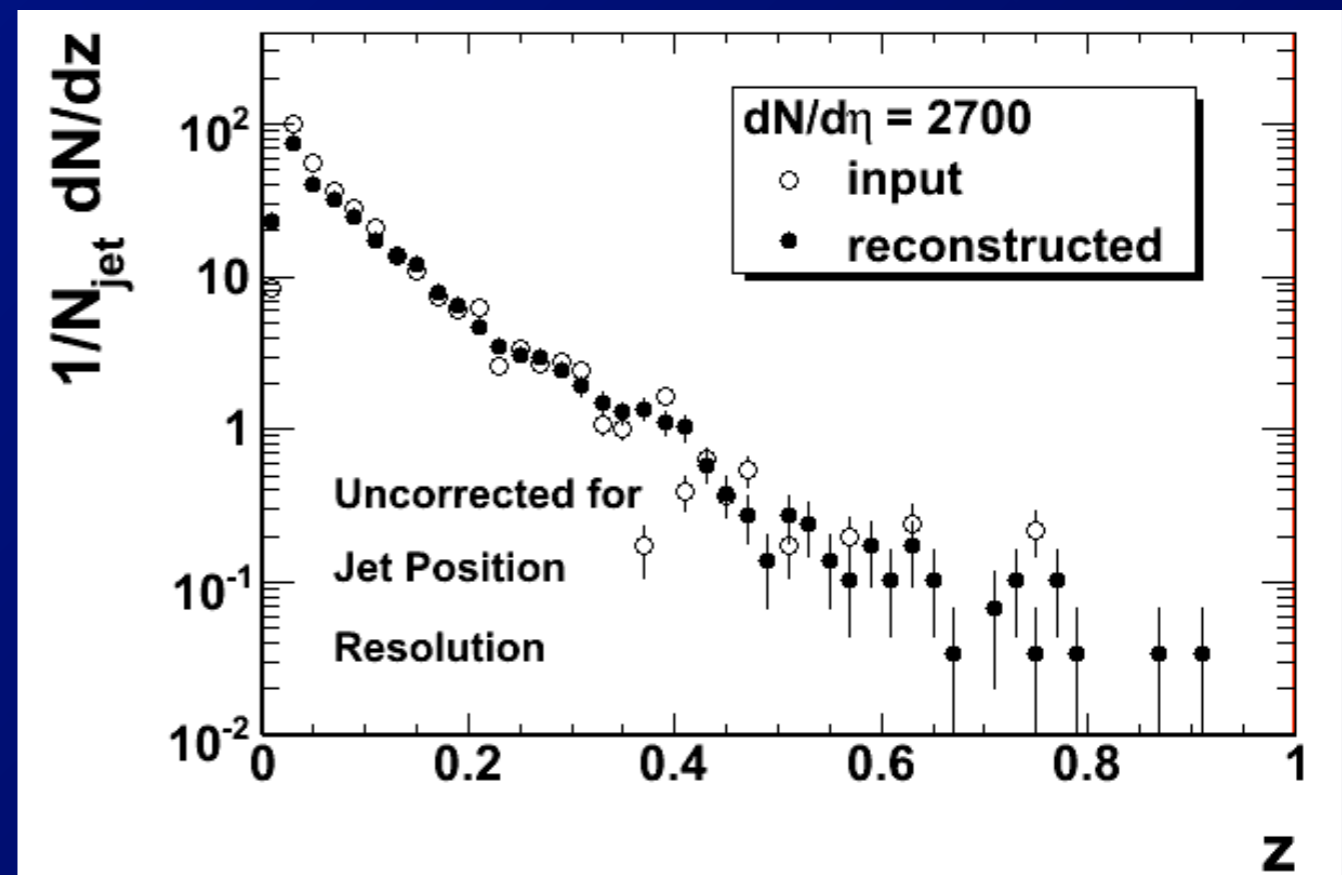
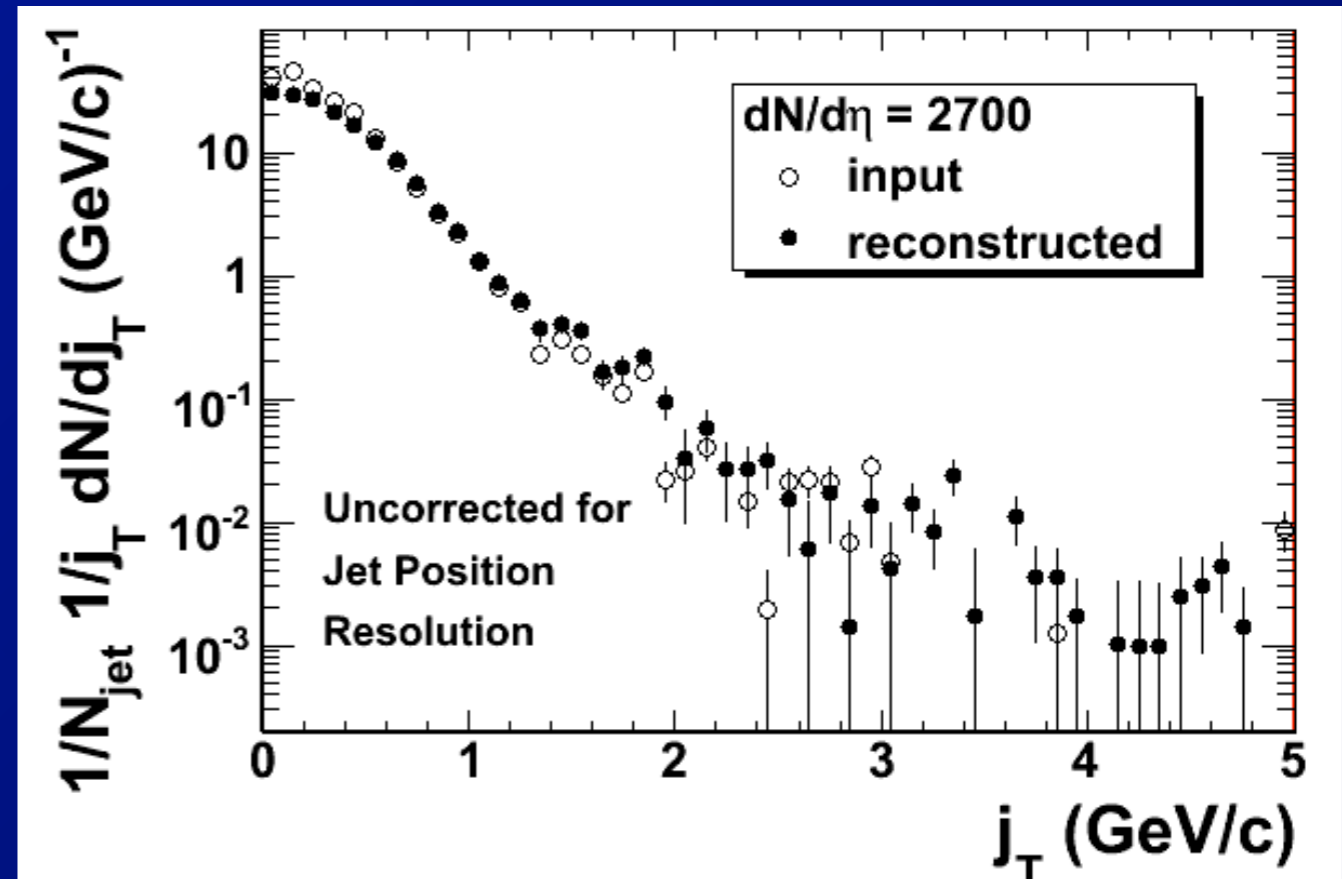


Artifact from
combining
different
PYTHIA
samples
(Q^2 cuts)

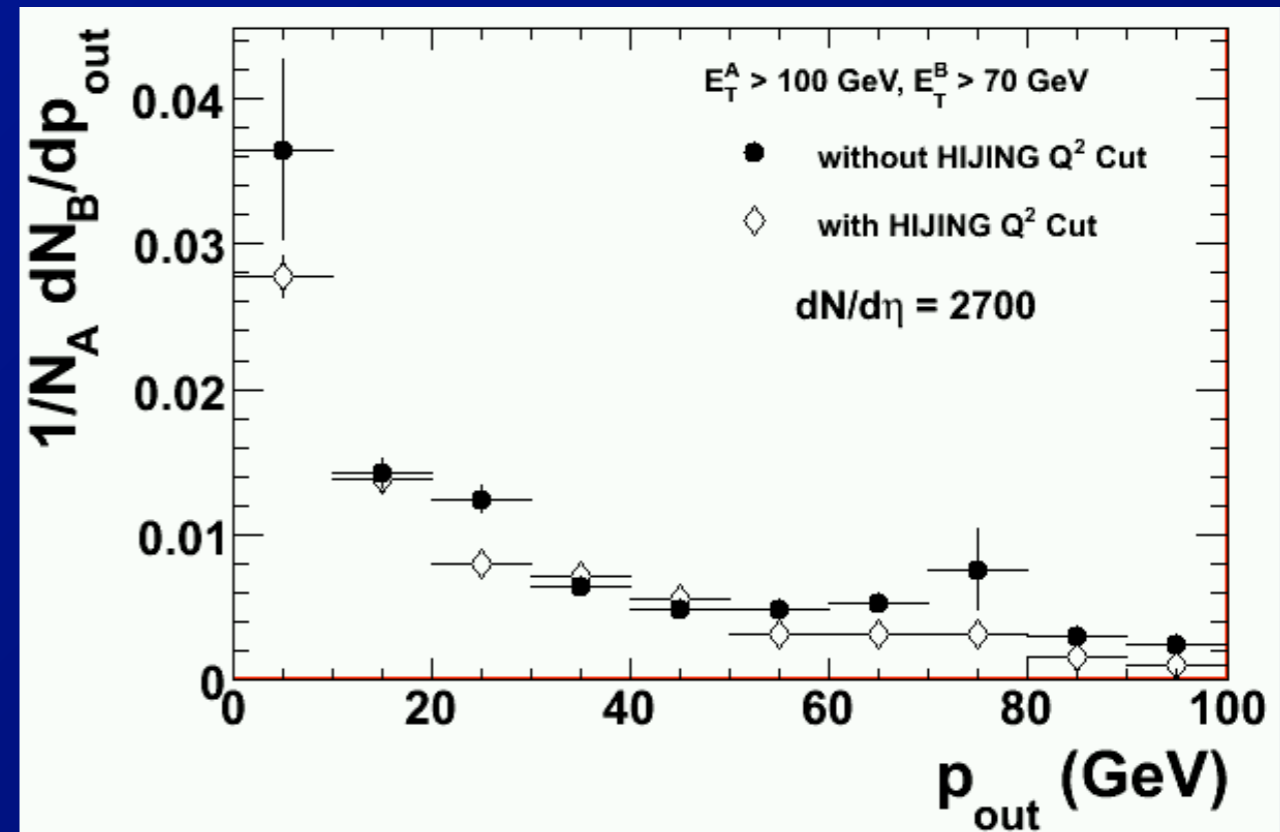
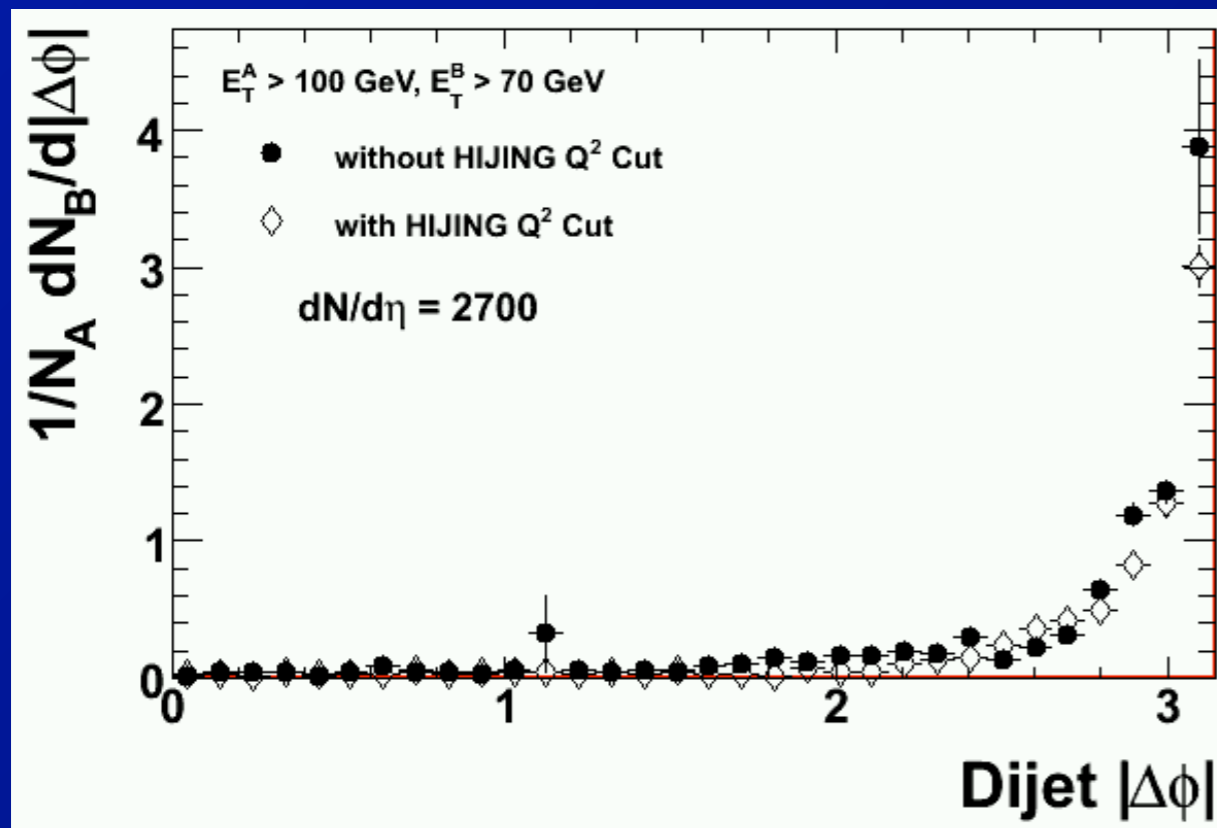
- Ratio of reconstructed to input spectrum
 - Jet spectrum reproduced within 20% above 70 GeV
⇒ Without corrections.
 - Modest centrality dependence.

Jet Fragmentation

- “Raw” evaluation of
 - J_T distribution
 - Fragmentation func.
 - $p_T > 2 \text{ GeV}/c$, $|\eta| < 2.5$
 - Jet $E_T^{\text{rec}} > 70 \text{ GeV}$
- With constant (for simplicity) 70% correction for tracking efficiency
 - ⇒ Reproduce shape and absolute yield
 - ⇒ Both J_T and $D(Z)$



Di-jet acoplanarity



- Evaluate di-jet $\Delta\phi$, p_{out} distribution

- $E_{Ta} > 100 \text{ GeV}$, $E_{Tb} > 70 \text{ GeV}$.

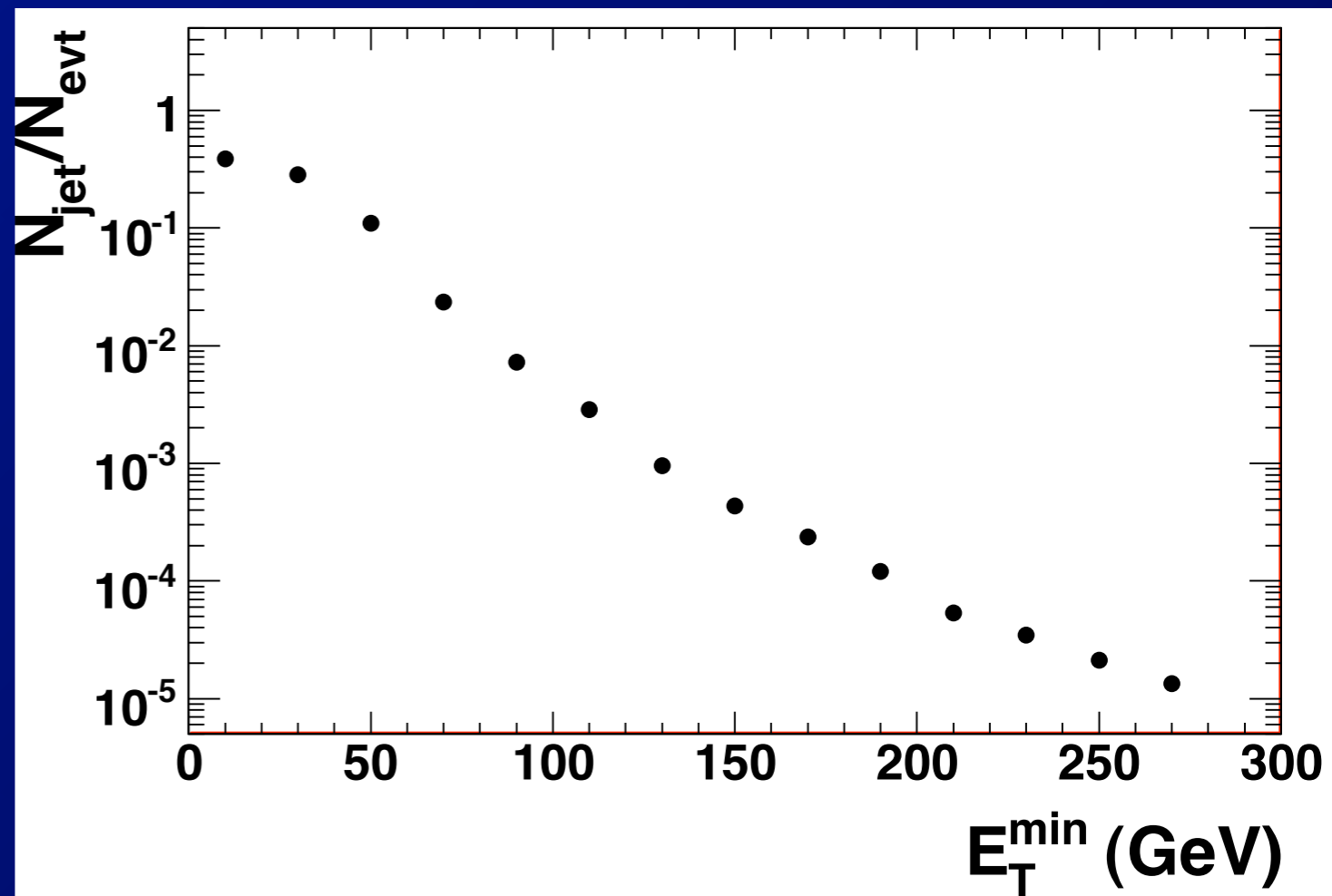
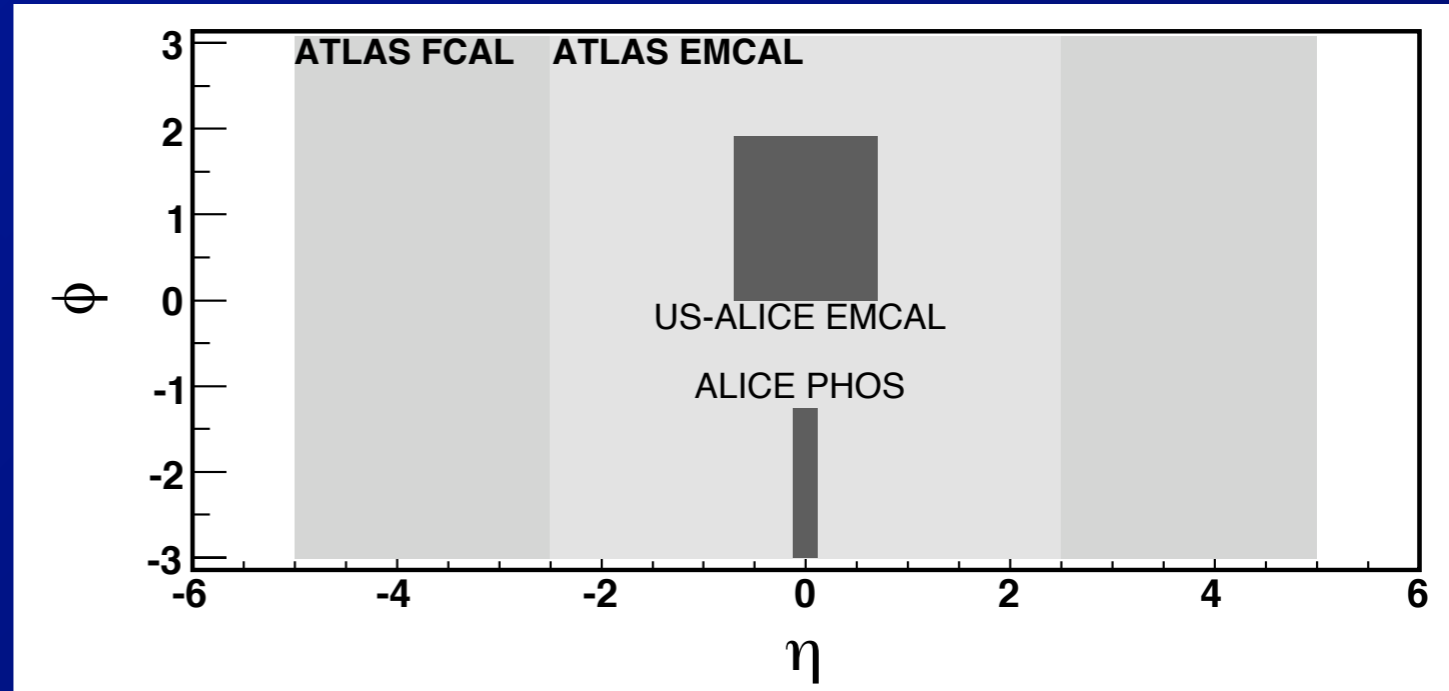
- With and without HIJING jets to evaluate confusion from uncorrelated jet pairs.

- ⇒ Negligible background (mostly pQCD)

- ⇒ Sensitive to momentum kick $\sim 10 \text{ GeV}/c$.

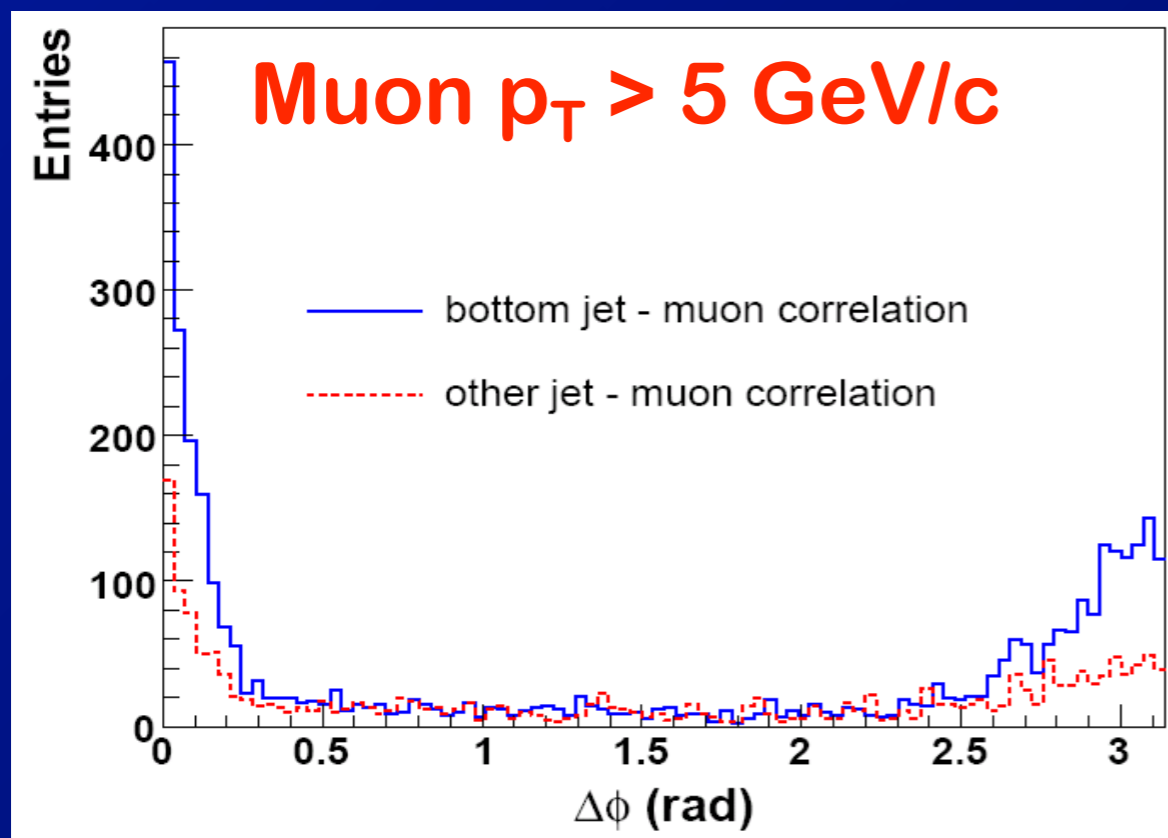
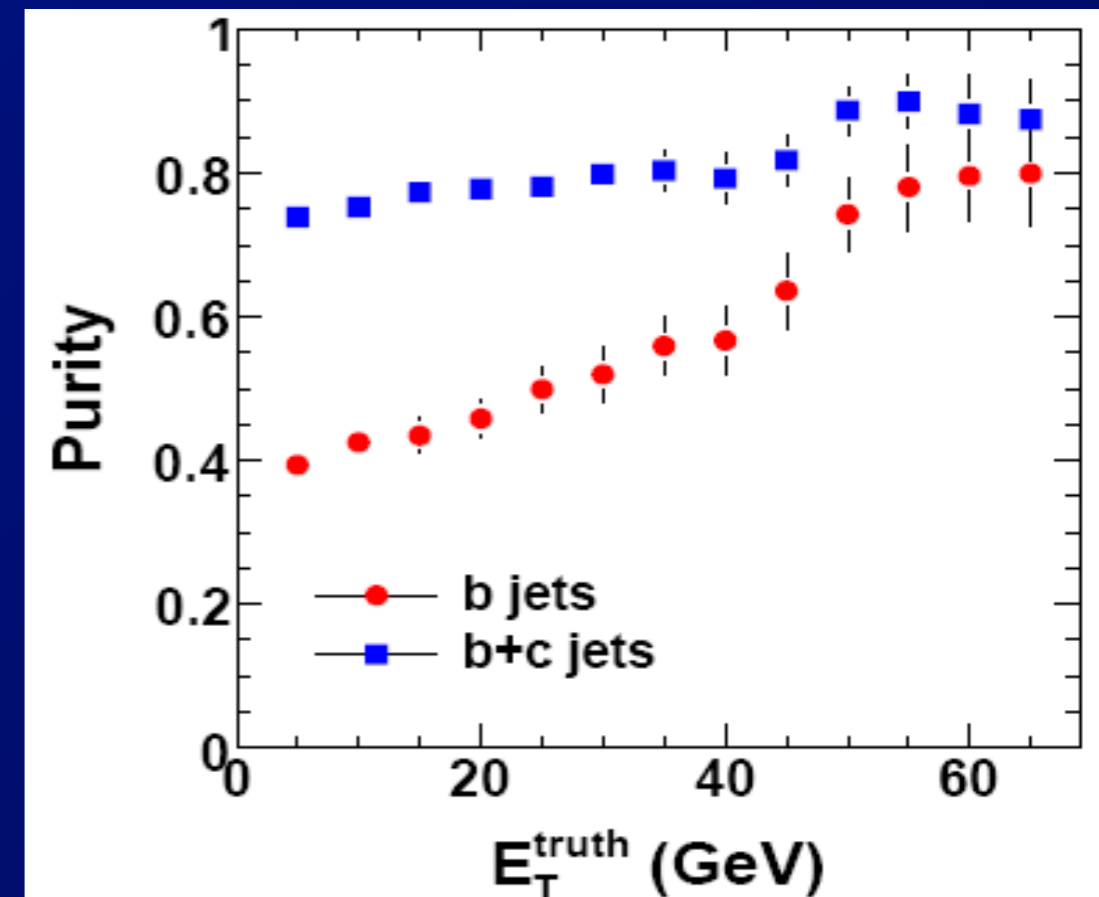
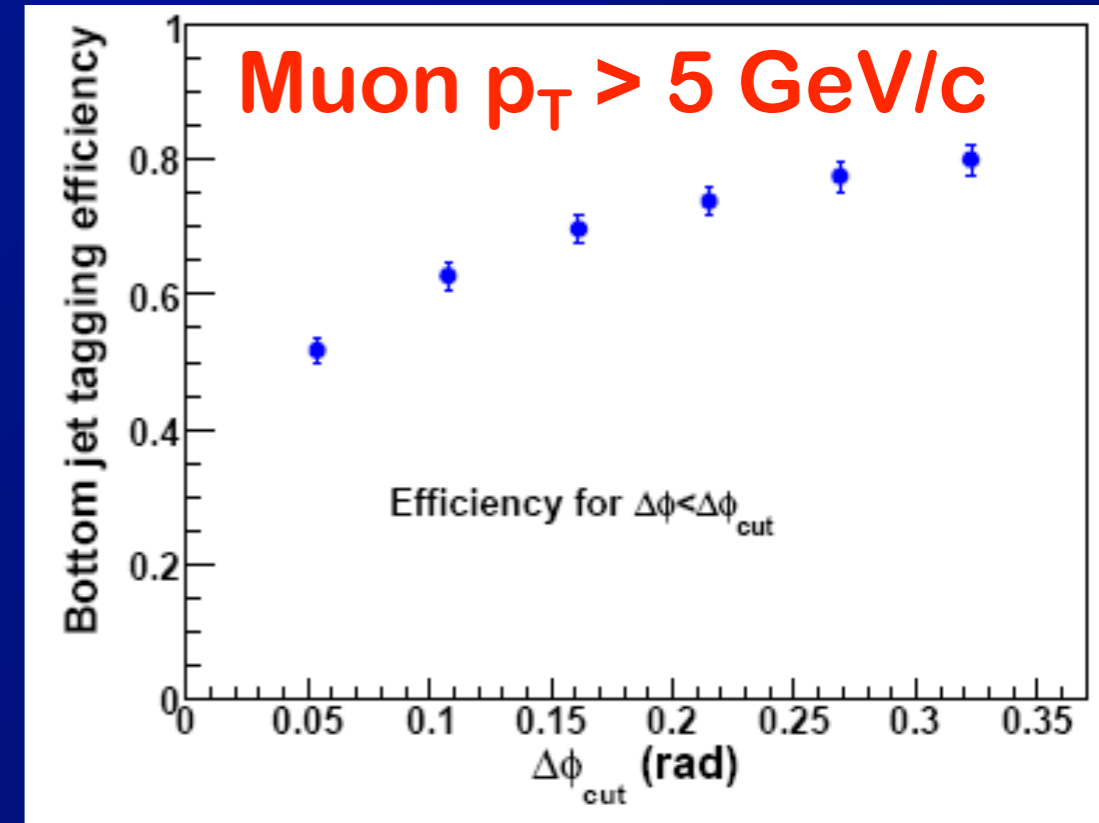
ATLAS Calorimeter Acceptance

- ATLAS has $\approx 100\%$ jet acceptance
- Rates per event
 - $\Rightarrow \sim 0.1$ @ 50 GeV
 - $\Rightarrow \sim 0.01$ @ 80 GeV
 - $\Rightarrow \sim 0.001$ @ 120 GeV
- Conservative full Pb+Pb run $\int \mathcal{L} dt$
 - $\Rightarrow 0.5 \text{ nb}^{-1}$
 - $\Rightarrow > 3 \times 10^9$ sampled min-bias events
- You can do the math

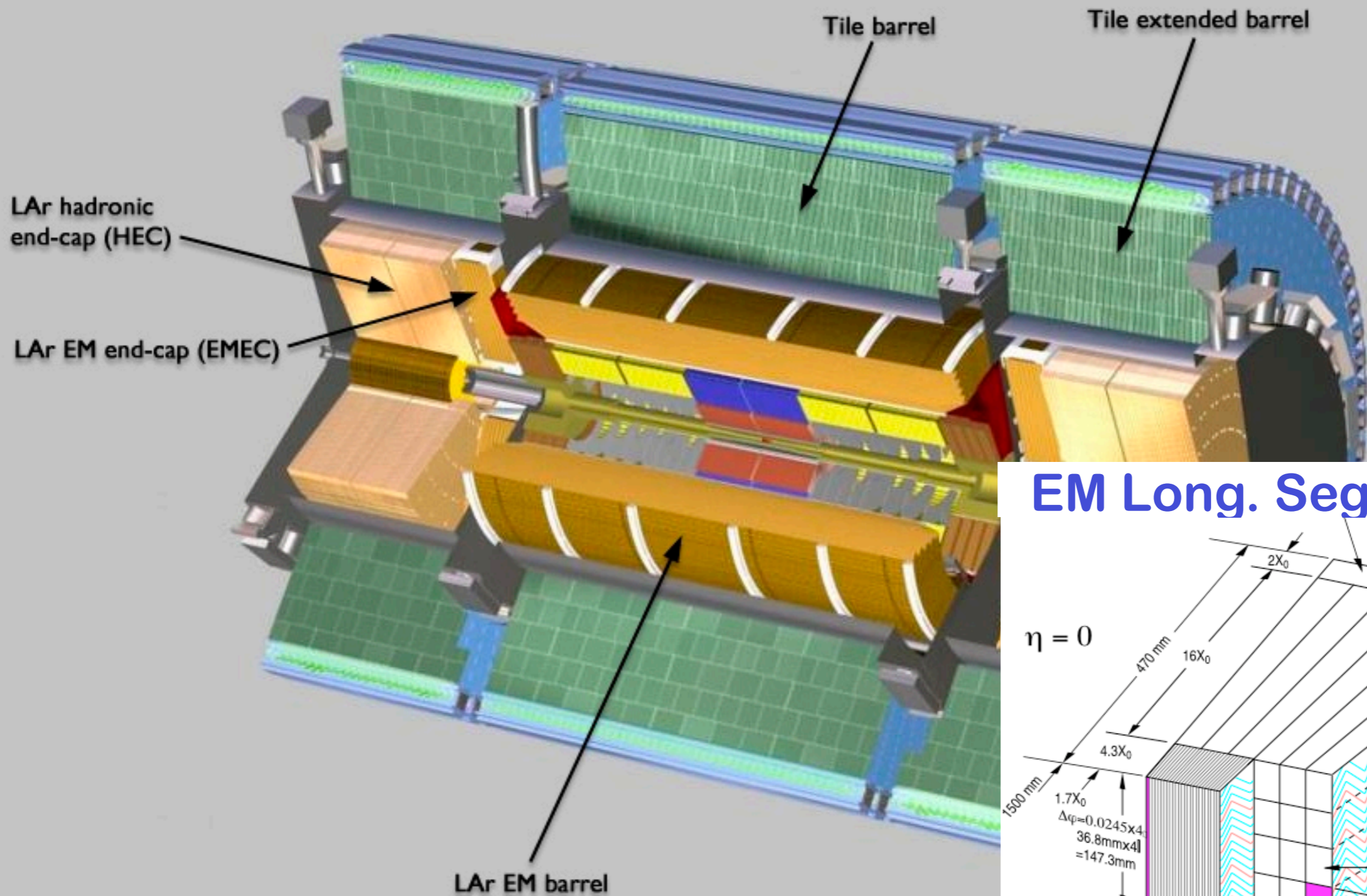


Tagged Heavy Quark Jets: First look

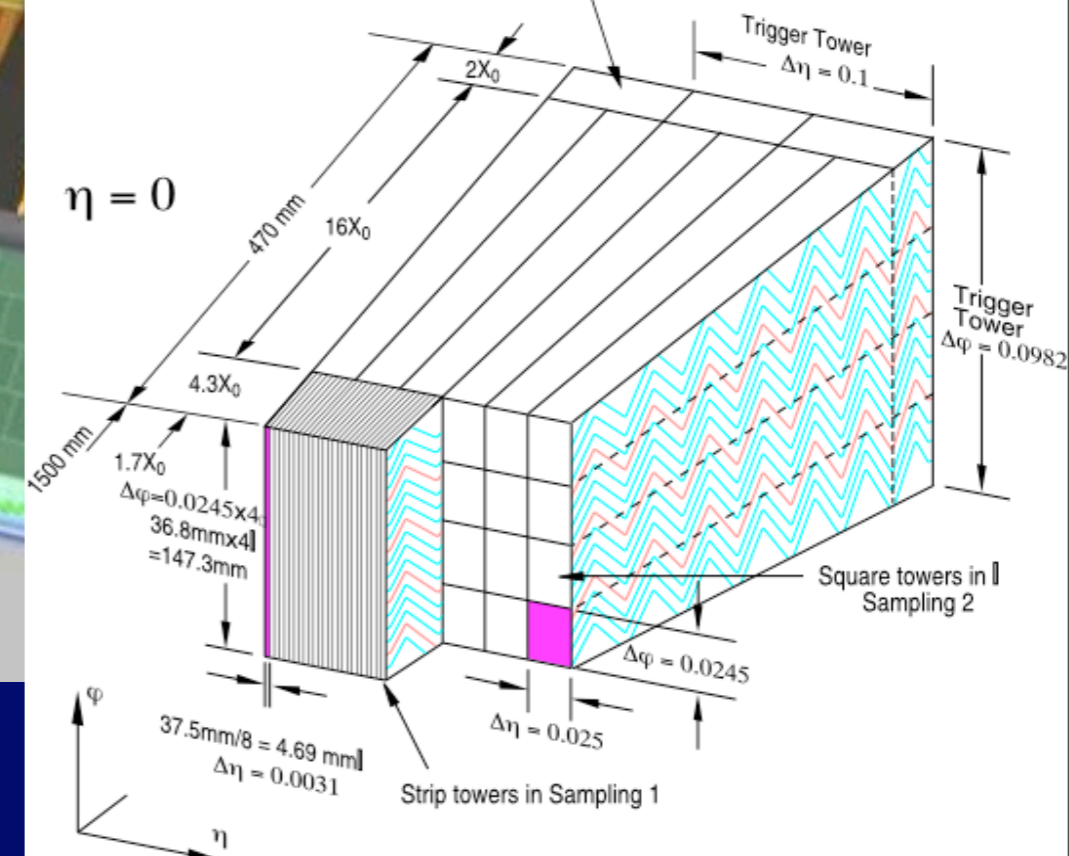
- Use muons to tag jets from heavy quark decays
 - Here jet $E_T > 35$ GeV
 - Tag both c and b (feature)
 - 20-30% impurity
- ⇒ Tagging straight-forward



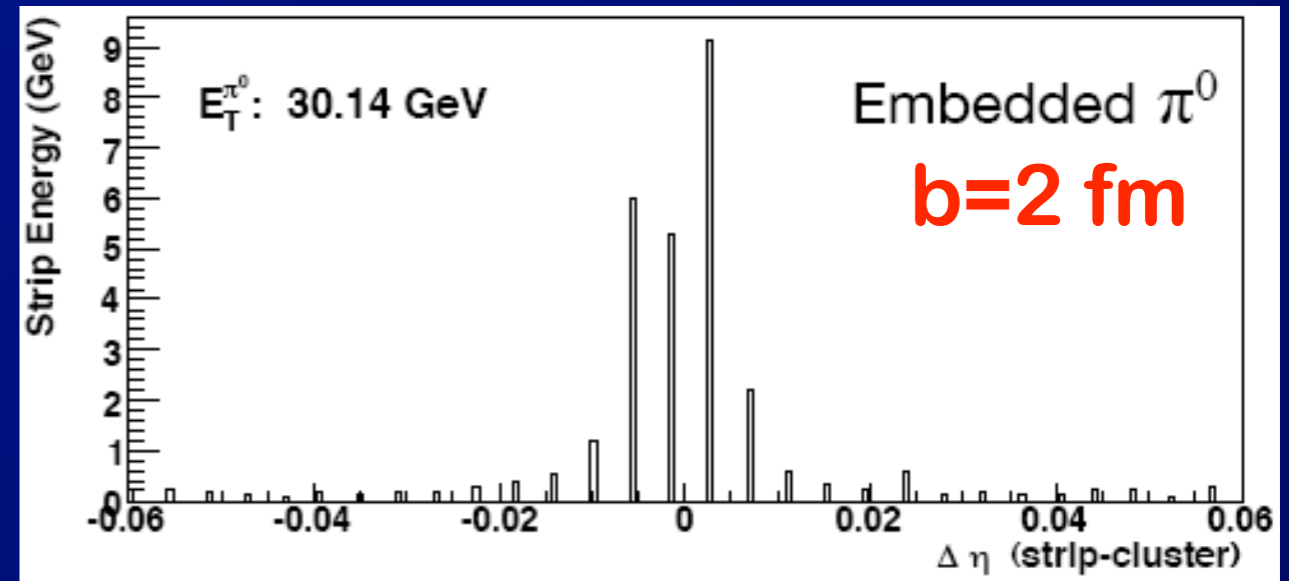
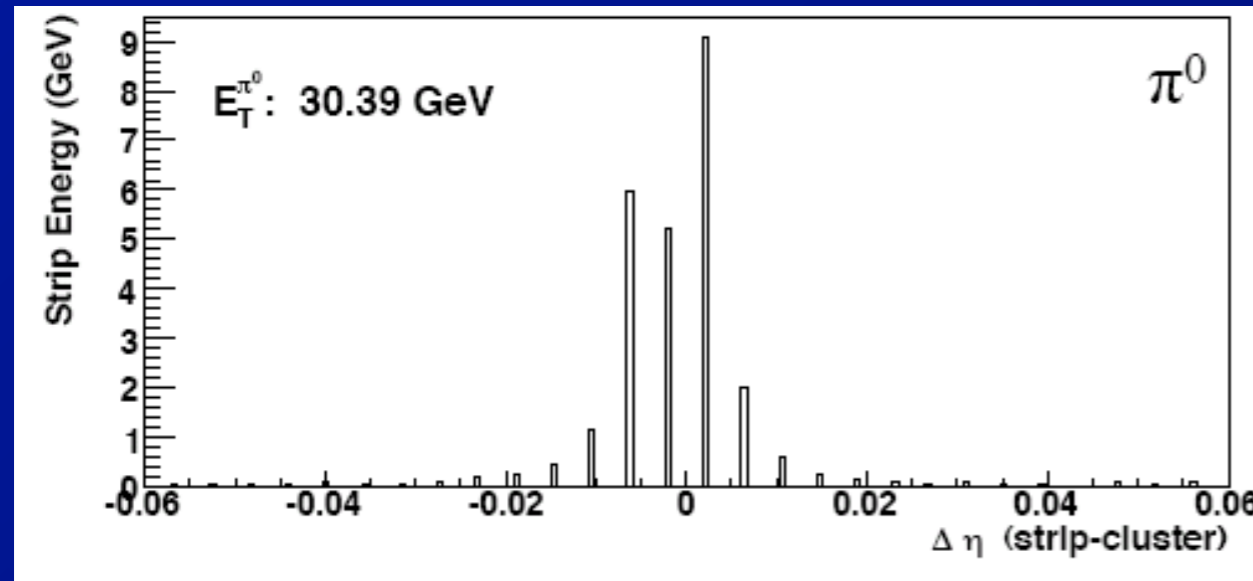
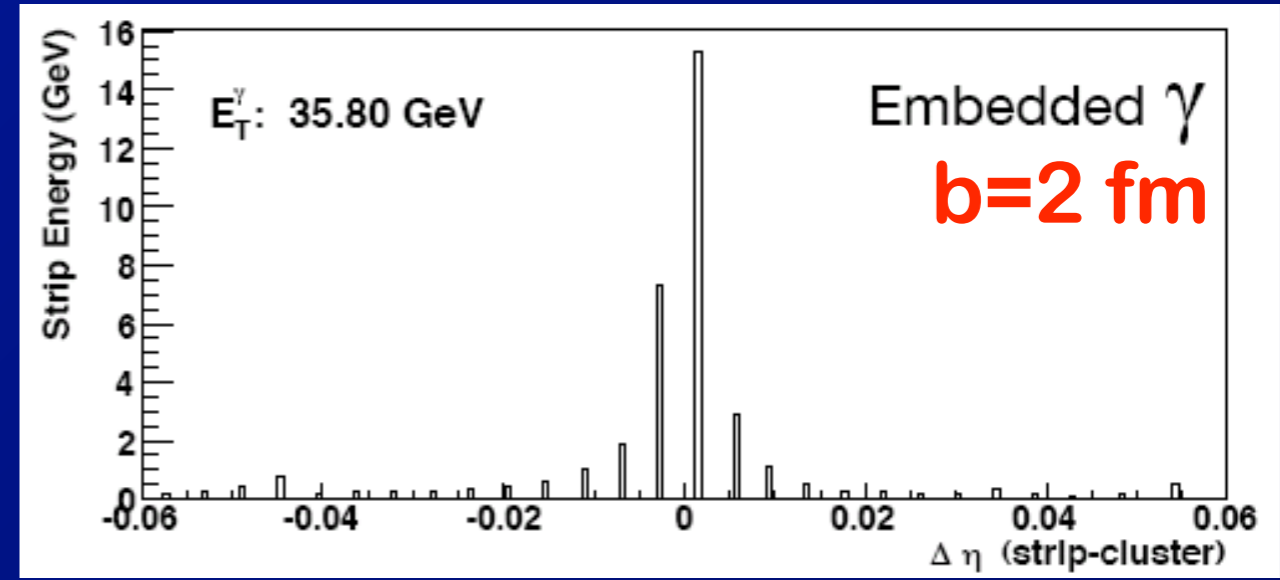
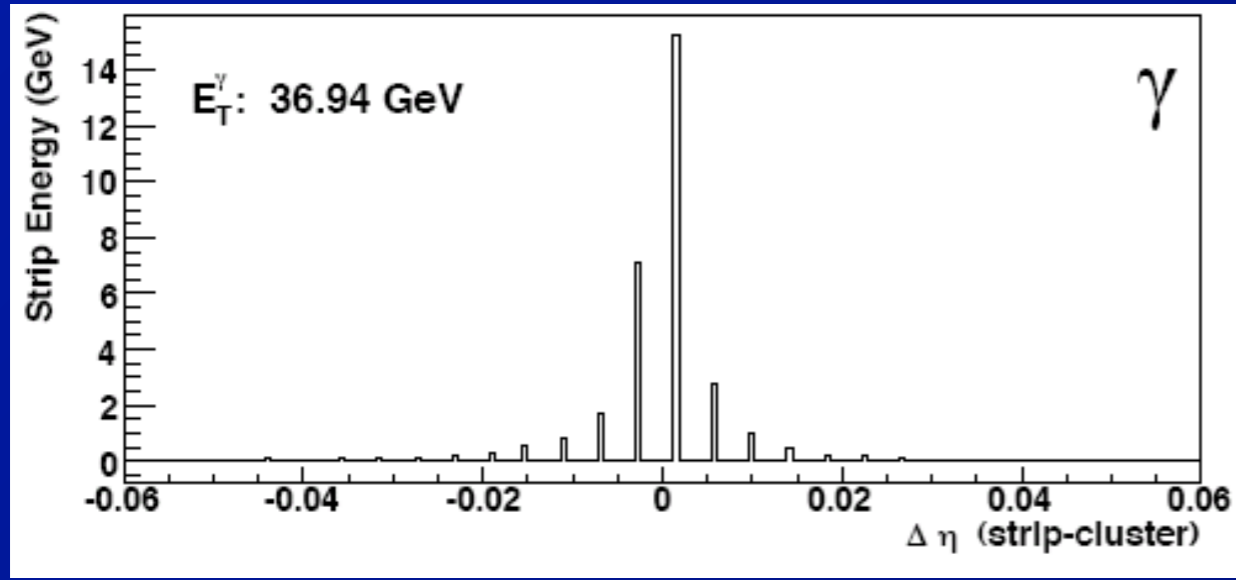
ATLAS Calorimetry: Long. Segmentation



EM Long. Segmentation

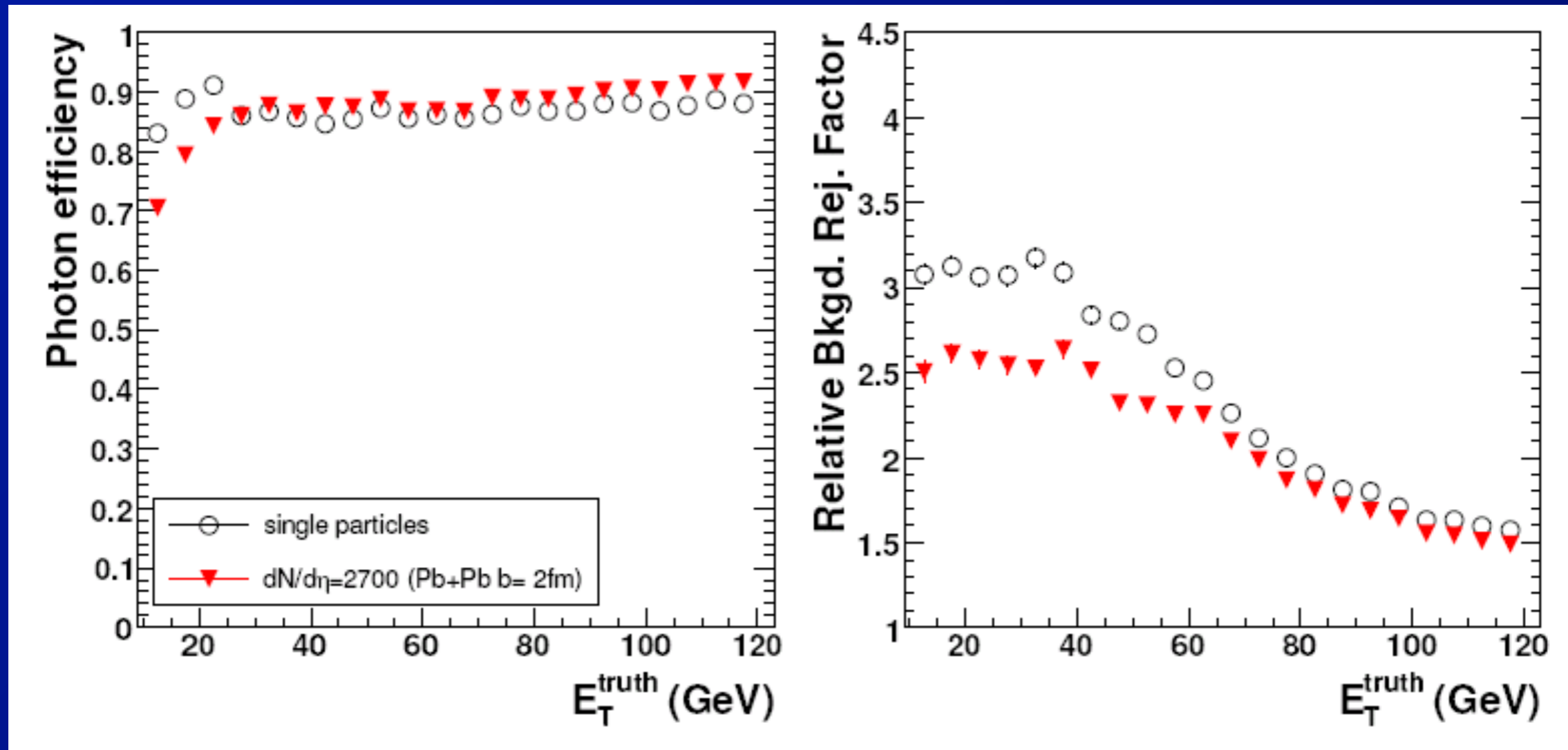


Prompt Photons: Method (1)



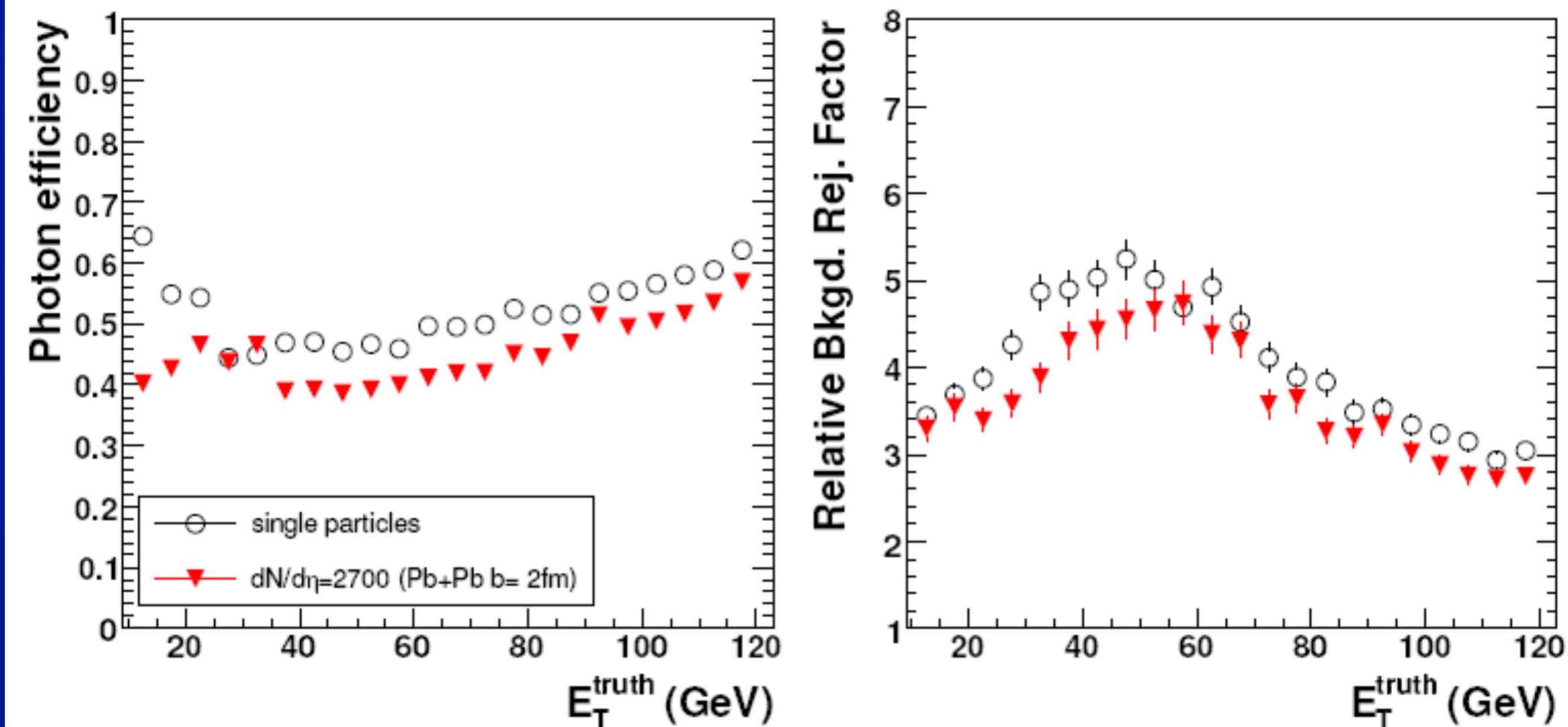
- First EM sampling layer has little background
 - Typically $< 50 \text{ MeV}$ in $b=2 \text{ fm Pb+Pb}$ ($dN_{\text{chg}}/d\eta = 2700$)
- Ability to separate single photons from π^0 , η
 - \Rightarrow Photon identification without isolation over $|\eta| < 2.4$

Photon Identification: Loose cuts



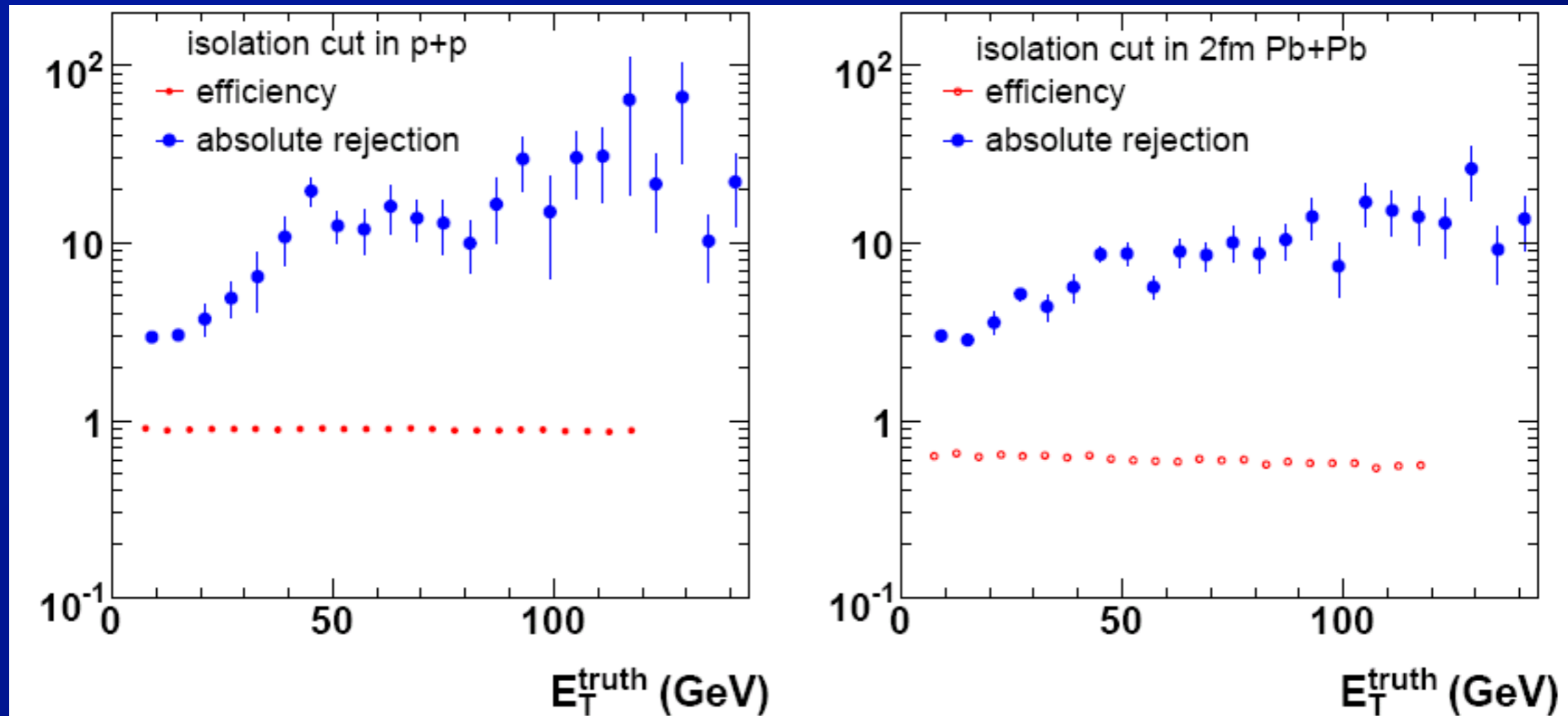
- Evaluate efficiency and (relative) rejection vs photon (EM cluster) energy
 - Relative rejection = Rejection \times efficiency
 - Rejection for neutral hadron produced EM clusters
- \Rightarrow Good efficiency, useful rejection beyond 100 GeV

Photon Identification: Tight cuts

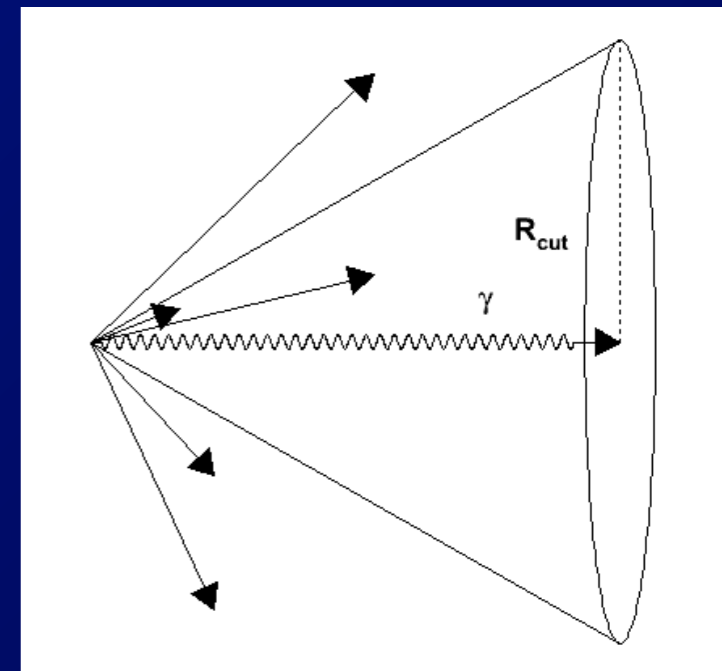


- Can get even better (relative) rejection against neutral hadrons with tighter cuts
 - At the expense of factor of 2 in statistics.
 - Can choose, depending on the analysis.

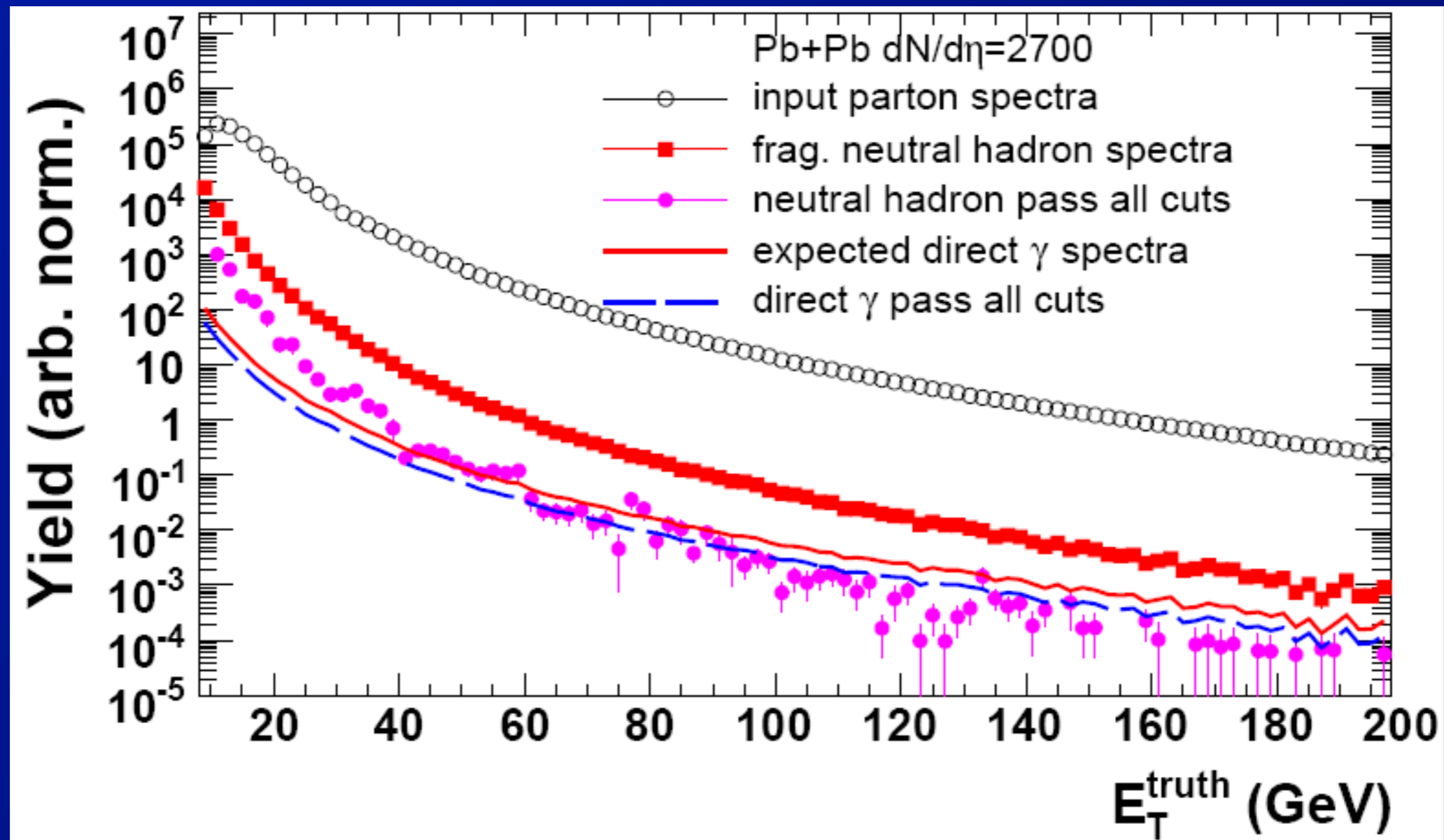
Prompt photons: isolation cuts



- Within cone of $R=0.2$
 - Require no particles with $p_T > \text{Cut}(E_\gamma)$.
- Within cone of $R=0.2$
 - Require $\Sigma E_T < \text{Cut}(\text{cent}, E_\gamma)$

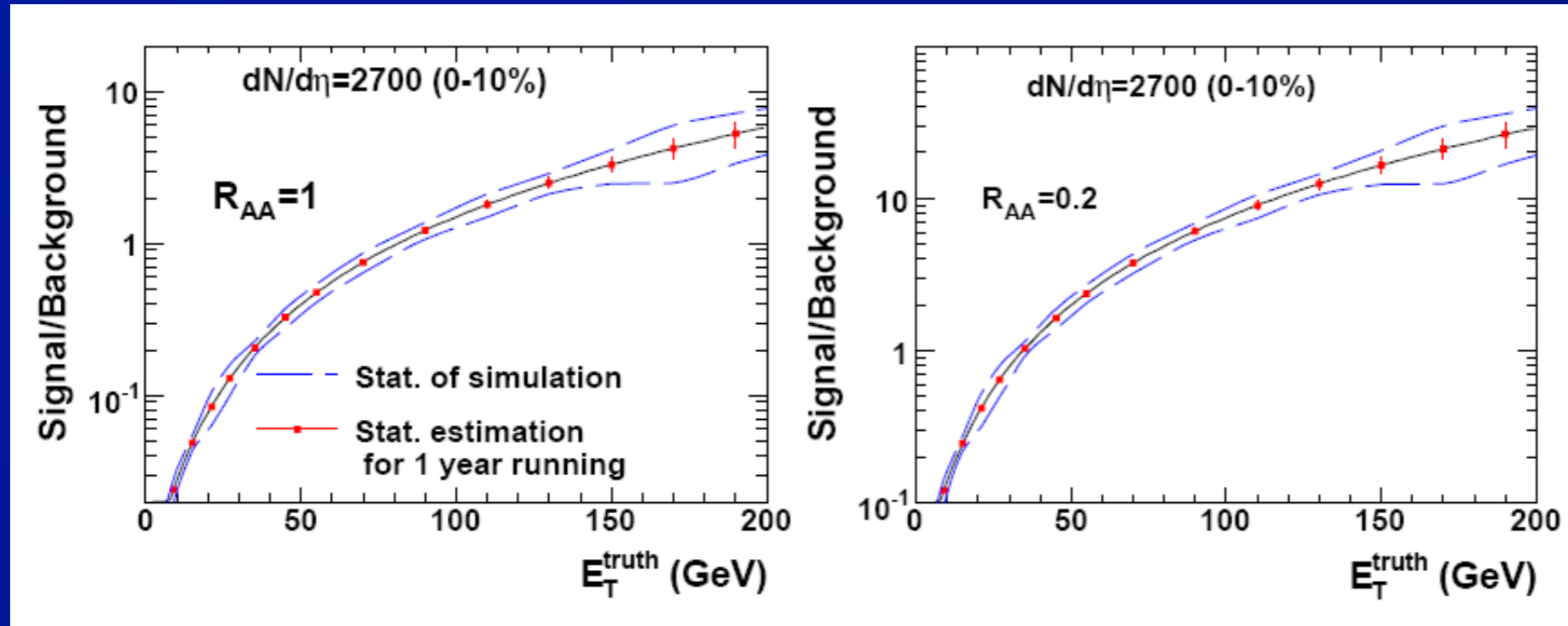


Photon Spectra

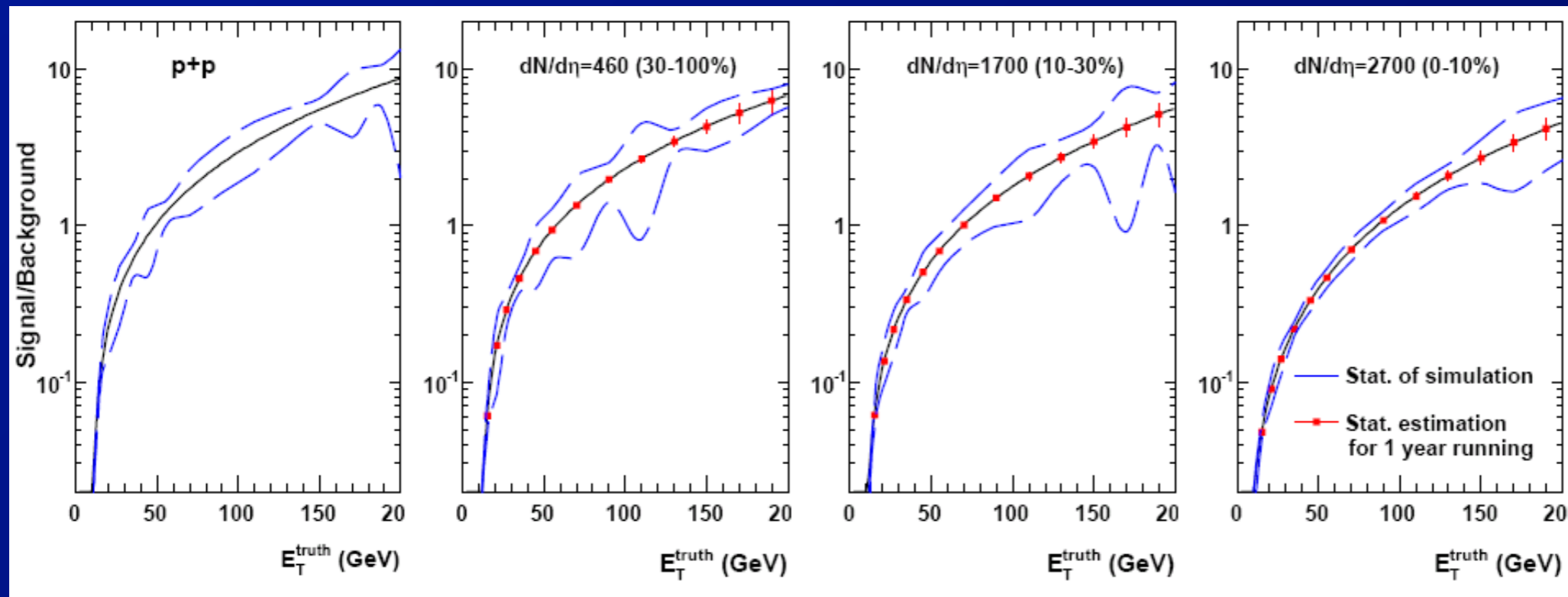


- Start with INCNLO for prompt photon, γ/π^0 .
- Use PYTHIA for jet events & fragments.
 - Normalize PYTHIA neutral hadron to INCNLO.
- Apply rejection(s) shown above ($R_{AA} = 1!$)

Prompt Photon S/B



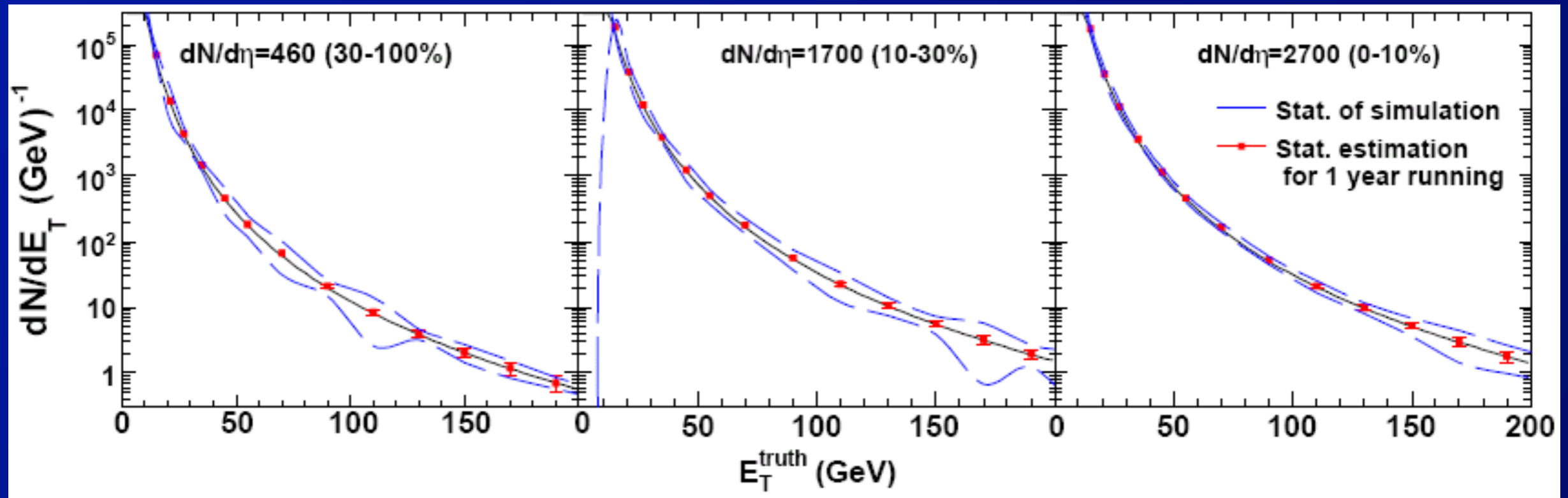
Red error bars indicate stat. errors in $0.5 \text{ nb}^{-1} \text{ int. luminosity}$



Neutral hadron $R_{AA}=1$

- “knee” in S/B curves at $\sim 30 \text{ GeV}$.

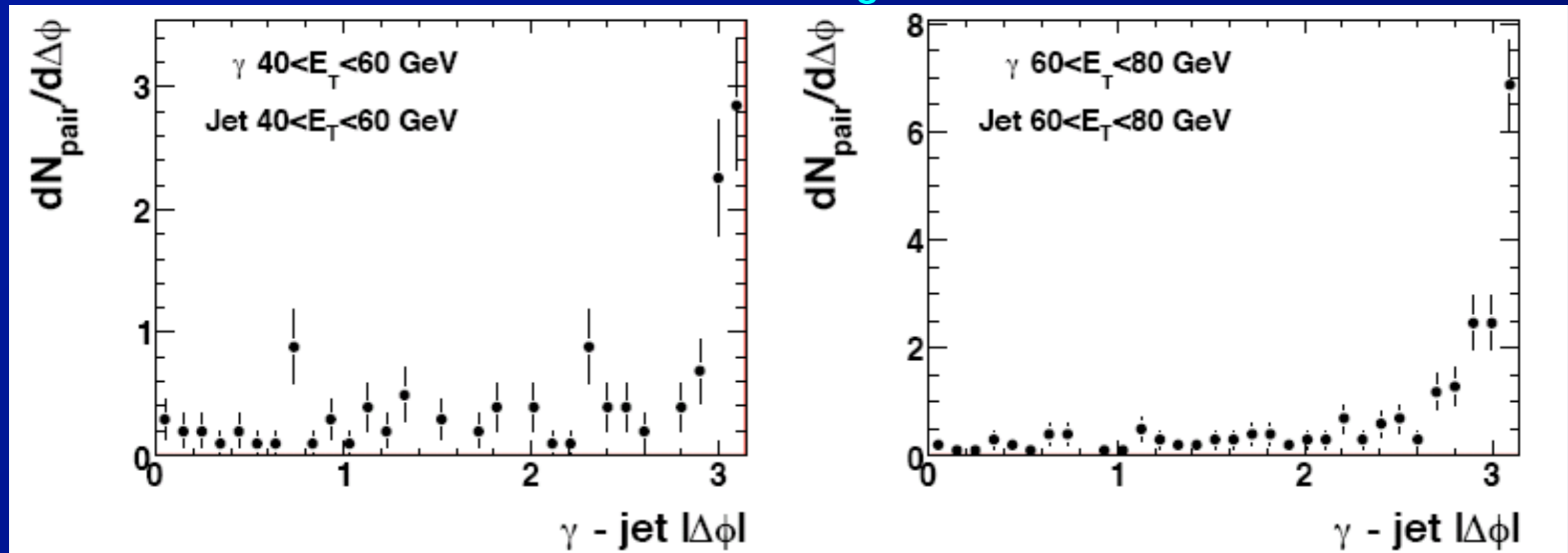
Prompt Photon Spectra



- Demonstration of what measured prompt photon spectrum will look like for 0.5 nb⁻¹ ($|\eta| < 2.4$)
 - Background measurement & subtraction errors
 - ⇒ All for neutral hadron $R_{AA} = 1$ (worst case)
- γ rates for 1 year LHC run (0.5 nb⁻¹):
 - ⇒ 100k for $p_T^\gamma > 30$ GeV, 10k for $p_T^\gamma > 70$ GeV

γ -jet Reconstruction

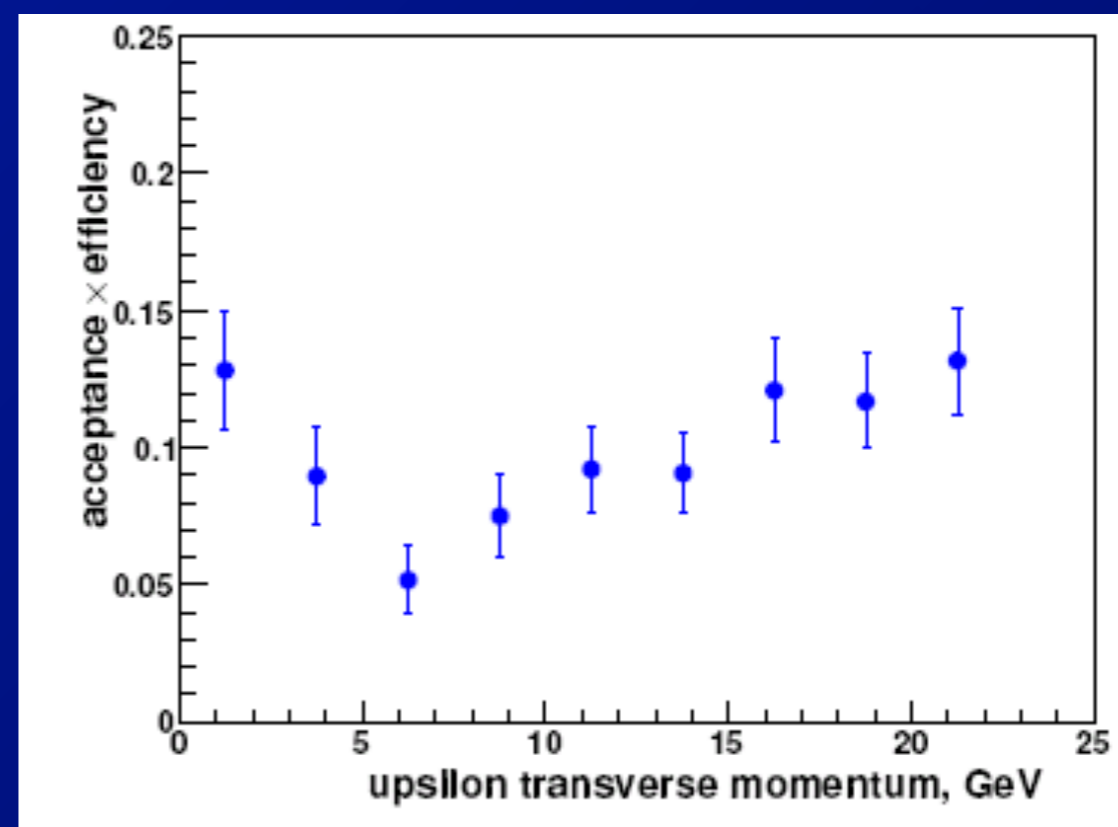
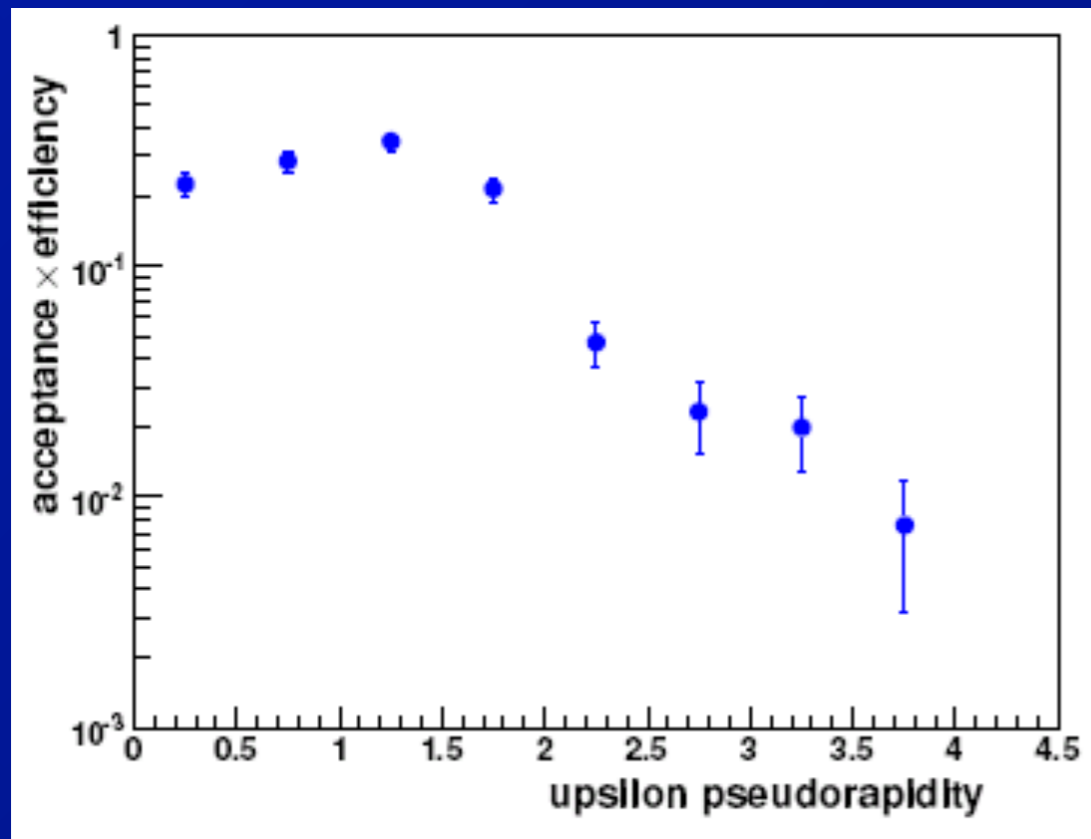
Central Pb+Pb (HIJING), $dN_{\text{chg}}/d\eta=2500$



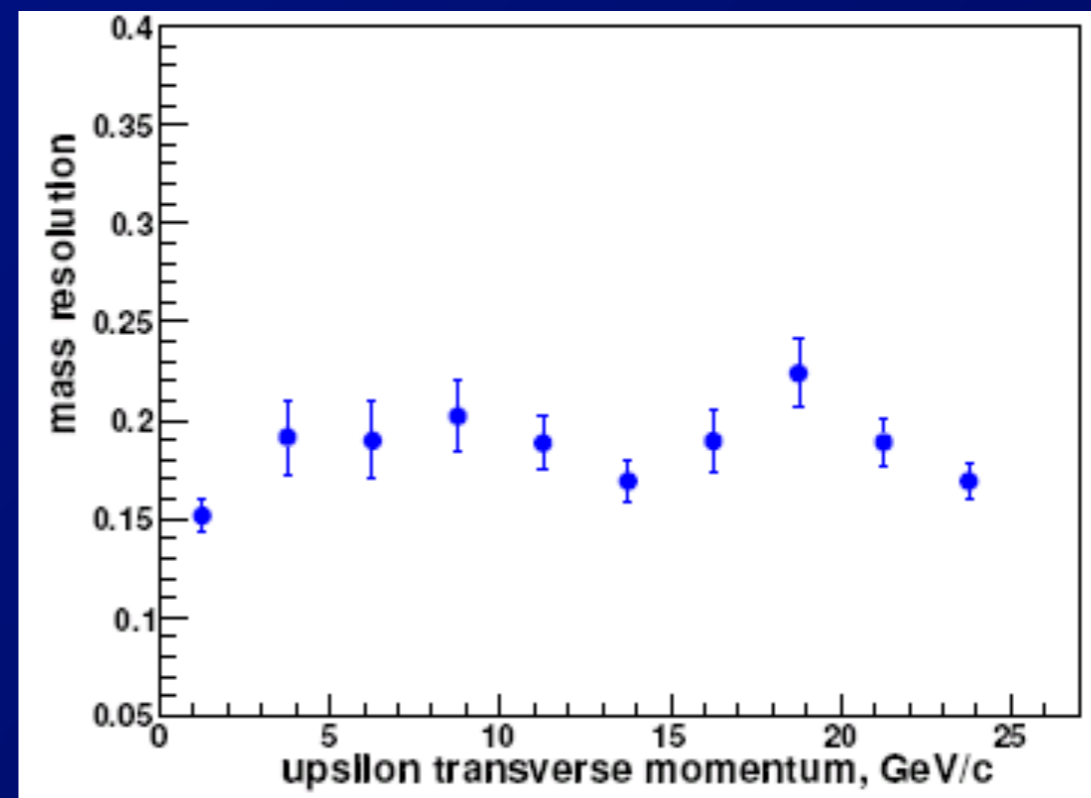
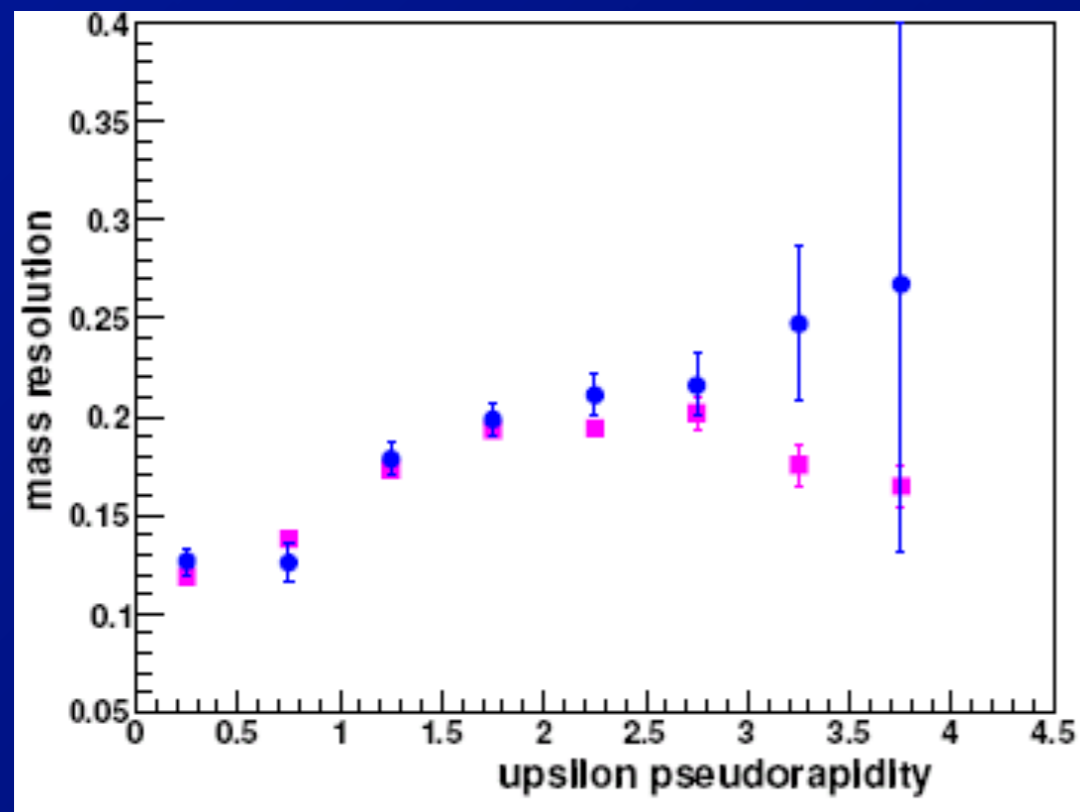
- Clean γ -jet $\Delta\phi$ dist. in central Pb+Pb (HIJING)
 - “Tail” primarily from pQCD
- Correlation can extend jet analysis to lower p_T
 - Discrimination against fake jets
- Clean measurement of modified $D(Z)$.

ATLAS Upsilon Reconstruction

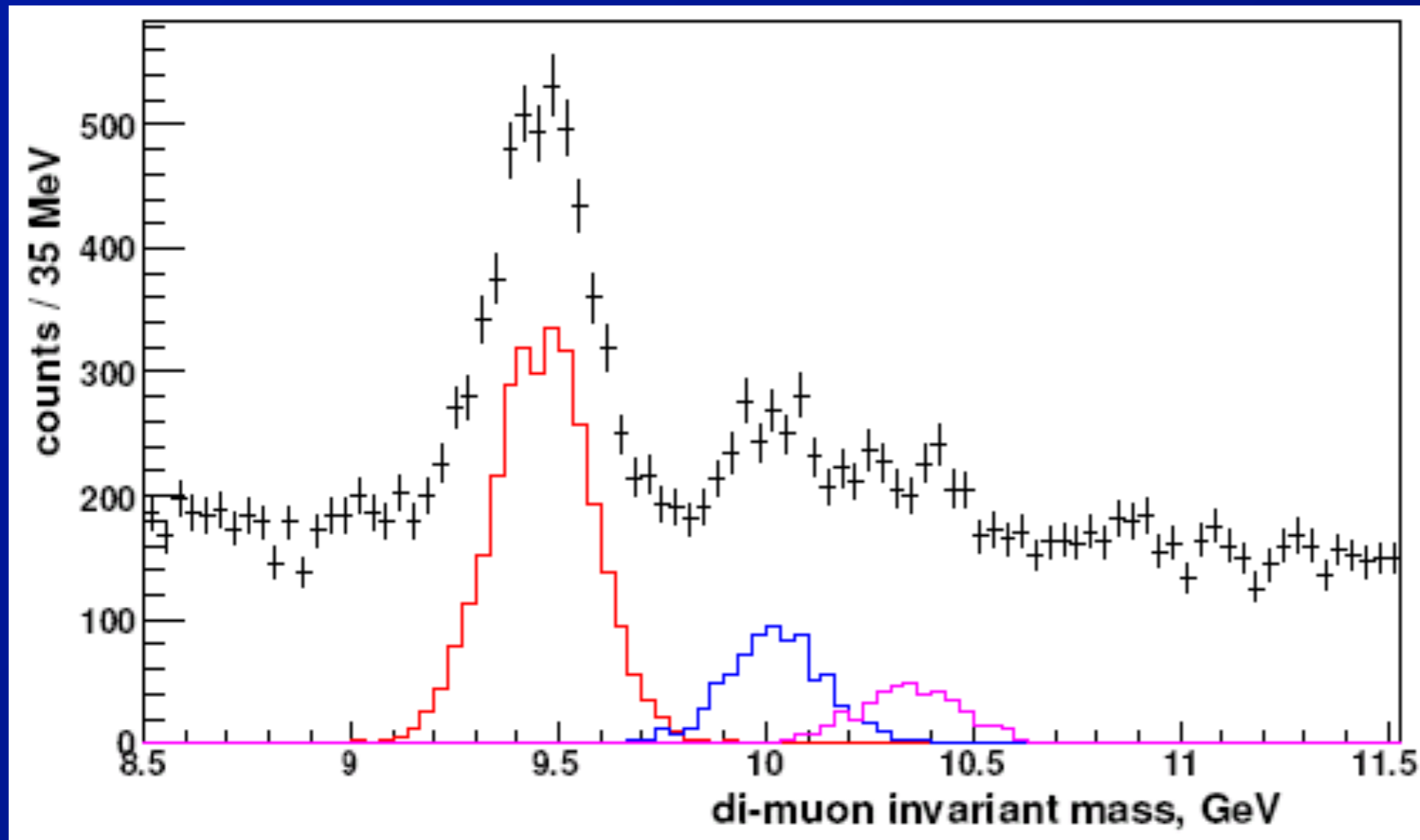
Acceptance x efficiency



Mass Resolution



ATLAS: Upsilon Measurement



Y, Y', Y'' in
estimated
background
for 0.25 nb^{-1}
integrated
luminosity.

Barrel region
only, $|\eta| < 1$.

- Signal and background (without quenching!)
- For barrel muon spectrometers (e.g.)
 - Average mass resolution, 125 MeV
 - 15 k total Y, Y', Y'' for 0.25 nb^{-1} .

J/ψ and Upsilon Rates

Y

Field $ \eta $ (max)	full 1	full 2	full 2.5	half 1	half 2	half 2.5
Acceptance x efficiency	4.7% (2.6%)	12.5% (8.1%)	17.5% (12.0%)	4.9% (2.6%)	13.8% (8.9%)	19.3% (13.4%)
Mass resolution (MeV)	123	145	159	126	162	176
S/B	0.3 (0.4)	0.2 (0.3)	0.2 (0.3)	0.3 (0.55)	0.2 (0.3)	0.2 (0.3)
$S/\sqrt{S+B}$	37 (31)	46 (45)	55 (55)	37 (34)	50 (48)	60 (60)
Rate/month	5700 (3100)	15000 (10000)	21200 (14600)	5900 (3100)	16800 (10800)	23400 (16300)

J/ψ

Field p_T (min) (GeV)	full 3	full 1.5	half 1.5
Acceptance x efficiency	0.055% (0.039%)	0.530% (0.151%)	1.100% (0.529%)
Mass resolution (MeV)	68	68	76
S/B	0.4 (0.5)	0.15 (0.2)	0.15 (0.25)
$S/\sqrt{S+B}$	56 (52)	113 (72)	164 (140)
Rate/month	11000 (8000)	104000 (30000)	216000 (104000)

Summary

ATLAS ready to make following measurements in Pb+Pb collisions @ LHC

- **Day-1 measurements of bulk observables**

- $dN/d\eta$, $dE_T/d\eta$
- Reaction plane via calorimetry, Si hits
- v_2 of charged particles, photons

- **Jets, jet fragmentation, di/multi-jets, heavy flavor tagged jets, over large η range:**

- single, multi-jets over $|\eta| < 5$
- Jet fragmentation over $|\eta| < 2.5$
 - ⇒ Using multiple reconstruction algorithms
- With good control over (relative) energy scale, yield

Summary (2)

ATLAS ready to make following measurements in Pb+Pb collisions @ LHC (cont)

- **Direct photons, γ -jet pairs**

- With direct rejection of π^0 , η decay γ
- With and without isolation
 - \Rightarrow Fragmentation, bremsstrahlung photons

- **Quarkonia**

- Clean Υ , Υ' , Υ'' separation for $|\eta| < 1$
- Clean Υ , Υ'/Υ'' separation over $|\eta| < 3.5$
 - \Rightarrow Over full p_T range
- J/ψ production at moderate/high p_T

ATLAS: Unique Contributions

- ATLAS has unique EM calorimetry
 - With longitudinal segmentation and fine transverse segmentation
 - Clean identification of photons (per above)
 - Better separation of EM/hadronic showers
 - Better handling of background
 - » Subtraction done layer-by-layer
 - » Background mostly in pre-sampler, 1st EM layer
 - » 1st EM layer sees photons with ~ no background
- ⇒ Better photon measurements (without isolation)
- ⇒ Better jet measurements
- ⇒ Better for measuring medium response
- ⇒ Over $|\eta| < 2.5$ (for fine sampling in EM layer 1)

ATLAS HI Institutions

Brookhaven National Laboratory, Upton, USA

Charles University, Prague, Czech Republic

Columbia University, New York, USA

University of Geneva, Geneva, Switzerland

IHEP, Moscow, Russia

IFJ PAN, Krakow, Poland

Iowa State University, USA

JINR, Dubna, Russia

MePHI, Moscow, Russia

Pontificia Universidad Catolica de Chile, Santiago, Chile

Santa Maria University, Valparaiso, Chile

Stony Brook University (Chemistry), Stony Brook, USA

Weizmann Institute, Rehovot, Israel

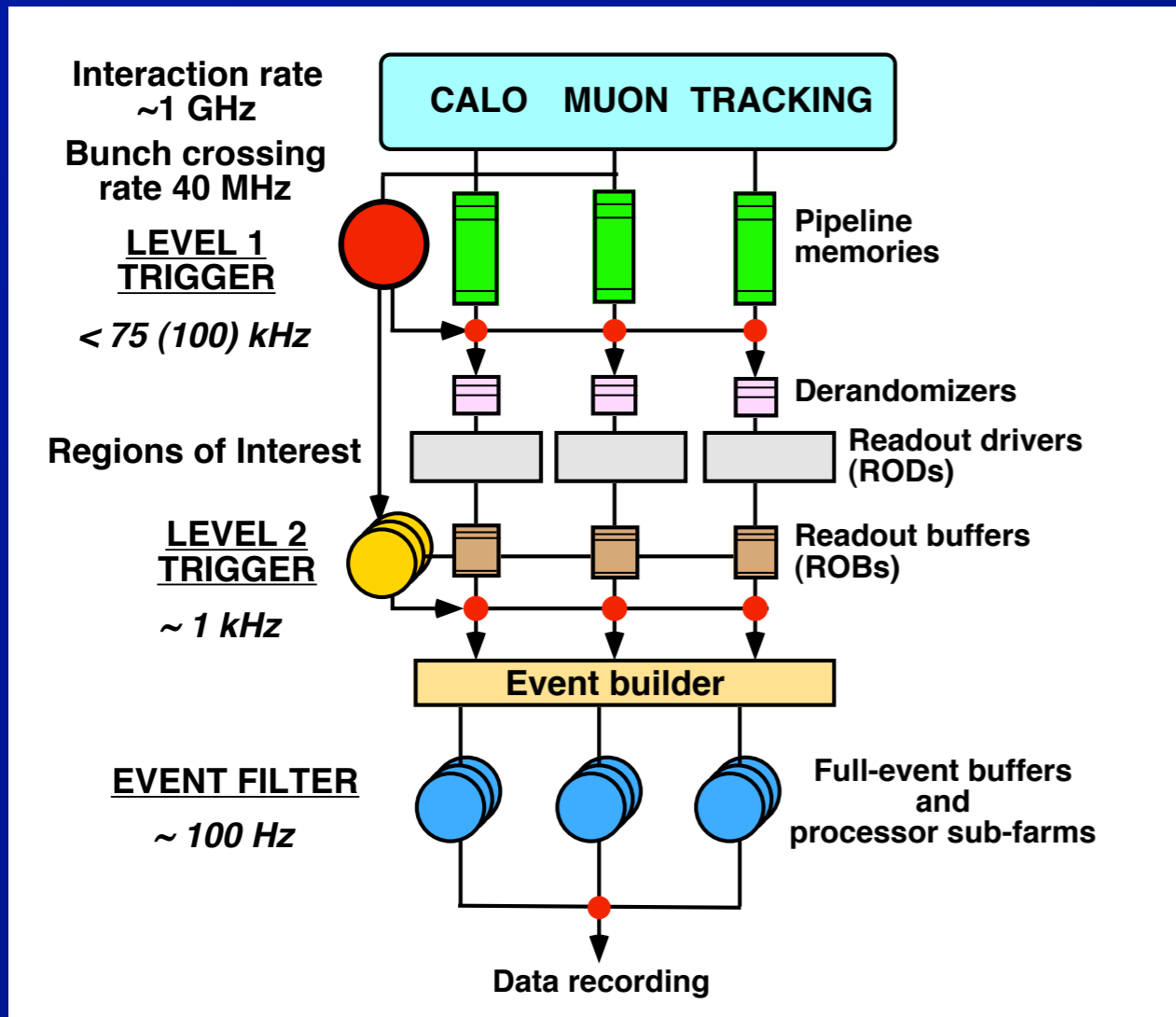
LHC Heavy Ion Operations

Jowett
QM08 Talk

Parameter	Units	Nominal	Early Beam
Energy per nucleon	TeV/n	2.76	2.76
Initial Luminosity L_0	$\text{cm}^{-2} \text{s}^{-1}$	$1 \cdot 10^{27}$	$5 \cdot 10^{25}$
No. bunches/bunch harmonic		592/891	62/66
Bunch spacing	ns	99.8	1350
β^*	m	0.5 (same as p)	1.0
Number of Pb ions/bunch		$7 \cdot 10^7$	$7 \cdot 10^7$
Transv. norm. RMS emittance	μm	1.5	1.5
Longitudinal emittance	eV s/charge	2.5	2.5
Luminosity half-life (1,2,3 expts.)	H	8, 4.5, 3	14, 7.5, 5.5

- **First heavy ion run expected end of 2009**
 - Assuming time & resources can be devoted to injector commissioning.
 - And dependent on success of p-p program
- ⇒ Which will start imminently.

ATLAS DAQ & Trigger



Example jet algorithm “slice”

L1: Calorimeter Jet ROIs

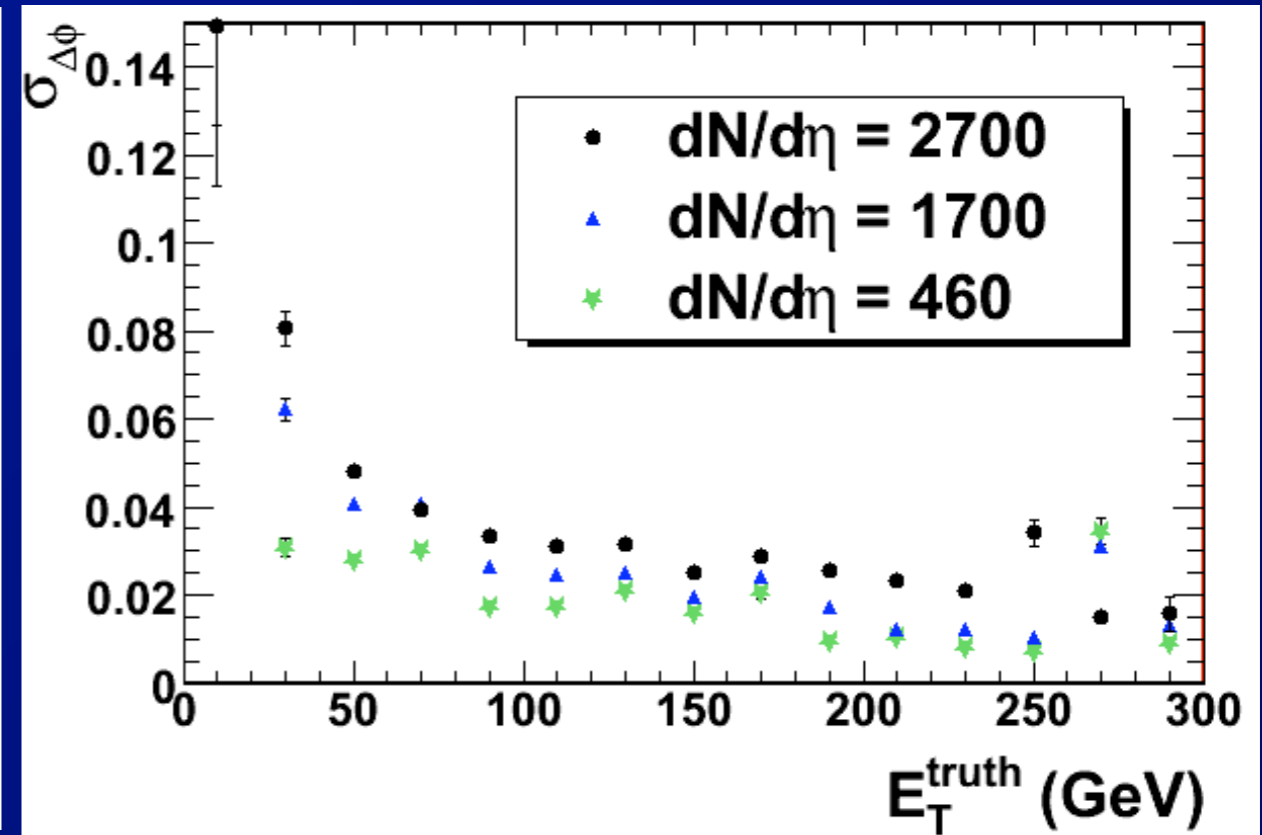
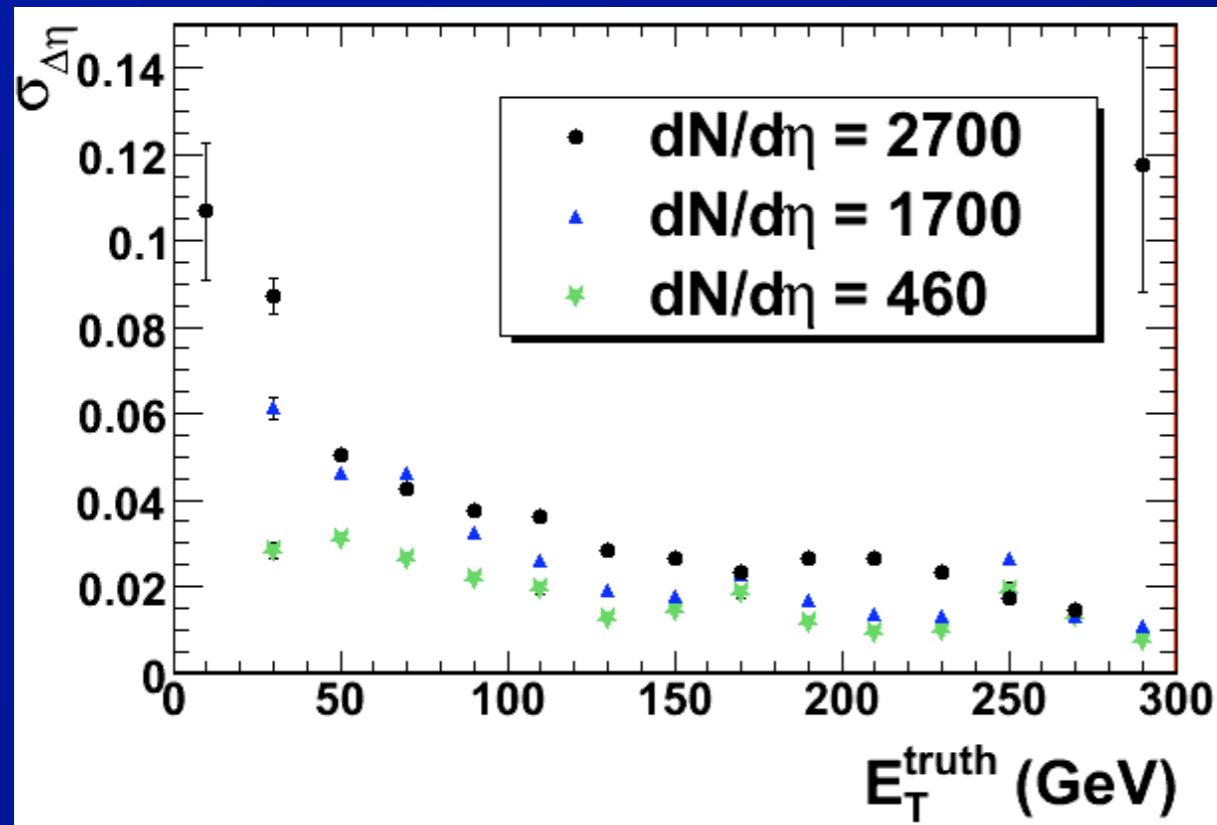
L2: Cone Jet analysis with L1 ΣE_T based background subtraction

EF: Full offline jet analysis cone, K_T , anti- K_T with background rejection

- **Min-bias trigger rate at $1 \times 10^{27} \sim 8$ kHz**
 - No rejection beyond minimum-bias required @ L1
 - ⇒ But L1 will produce “regions of interest” (ROIs)
 - Level-2 and Event Filter (\equiv Level-3) use ROIs to seed processor-based calculations, trigger decisions.

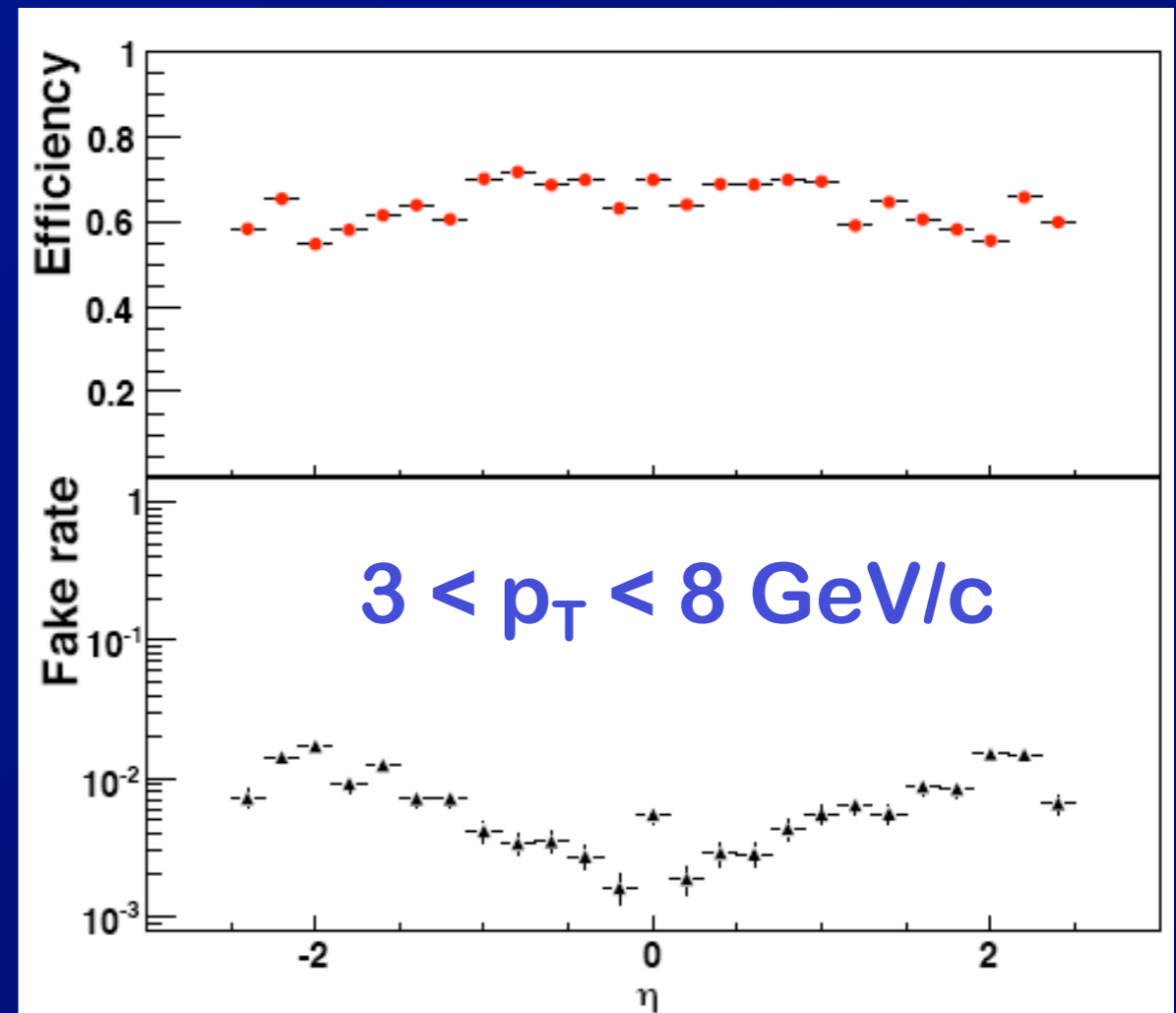
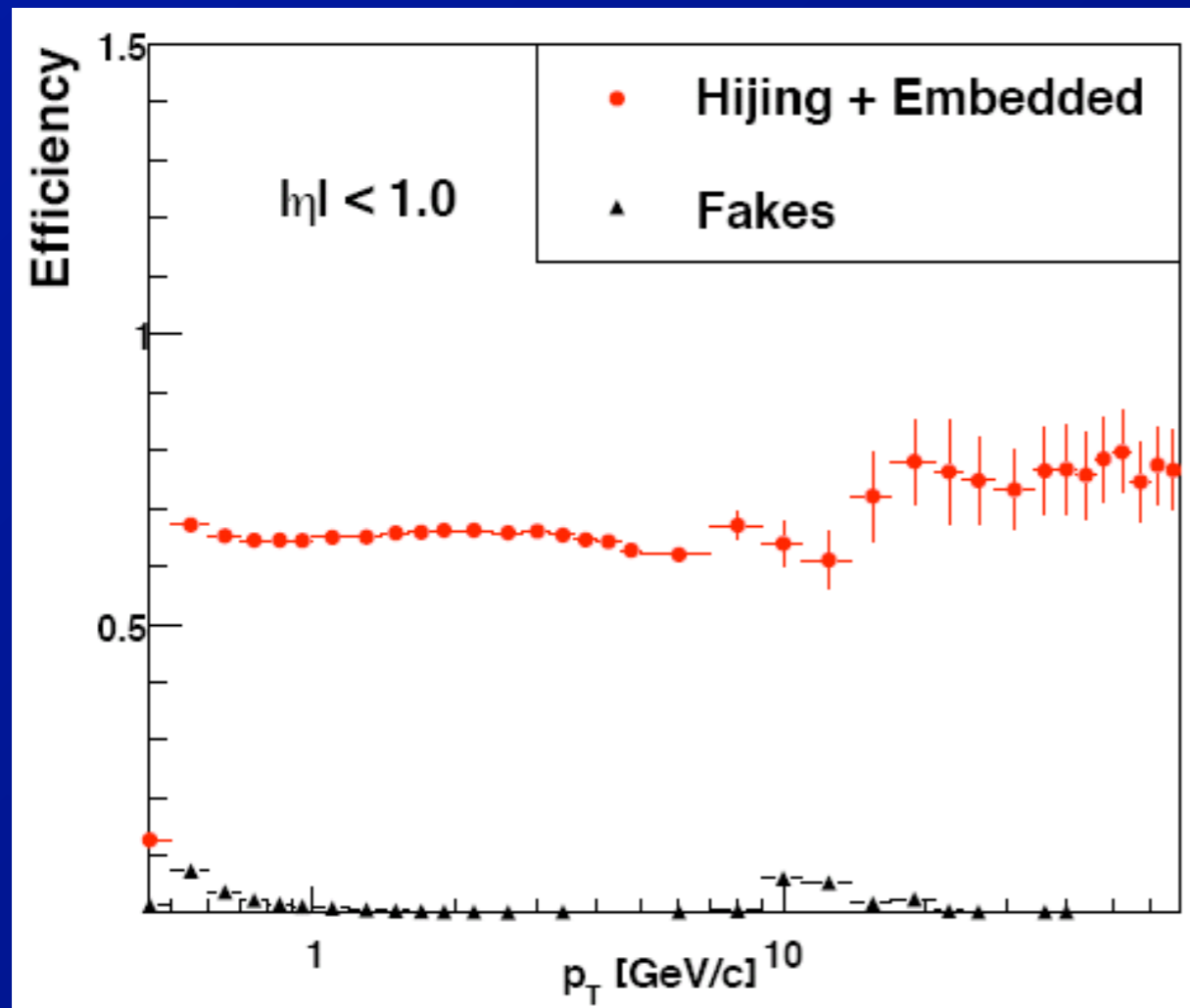
Backup Slides

Cone Jet Angular Resolution



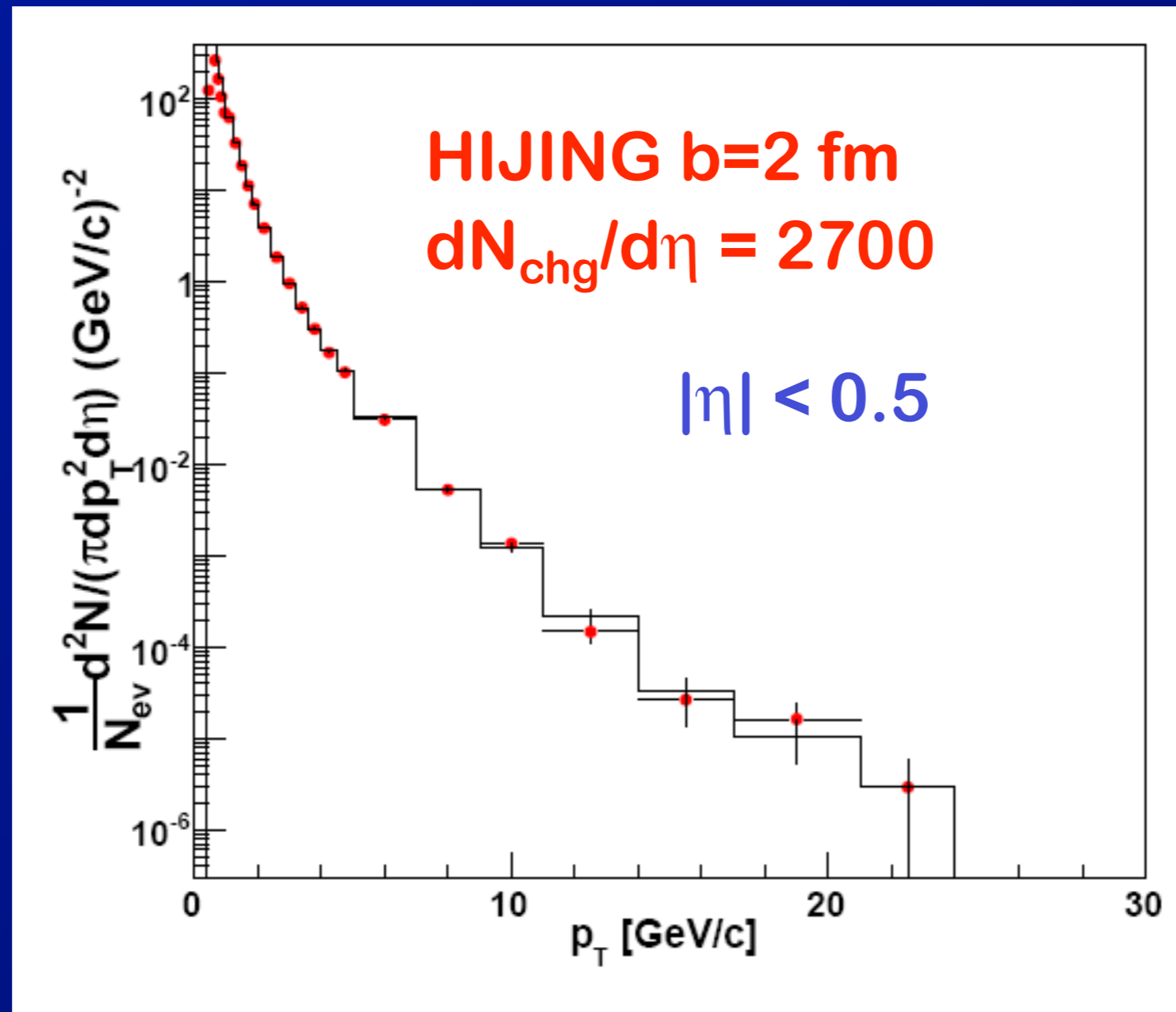
- Cone jet algorithm in HIJING Pb+Pb
 - With effects from uncorrelated jets in same event
- Angular resolution ~ 0.04 at 50 GeV.
 - Good measurement of di-jet, γ -jet $\Delta\phi$ (e.g.)
 - Minimal distortion of hadron J_T distribution

Tracking Performance



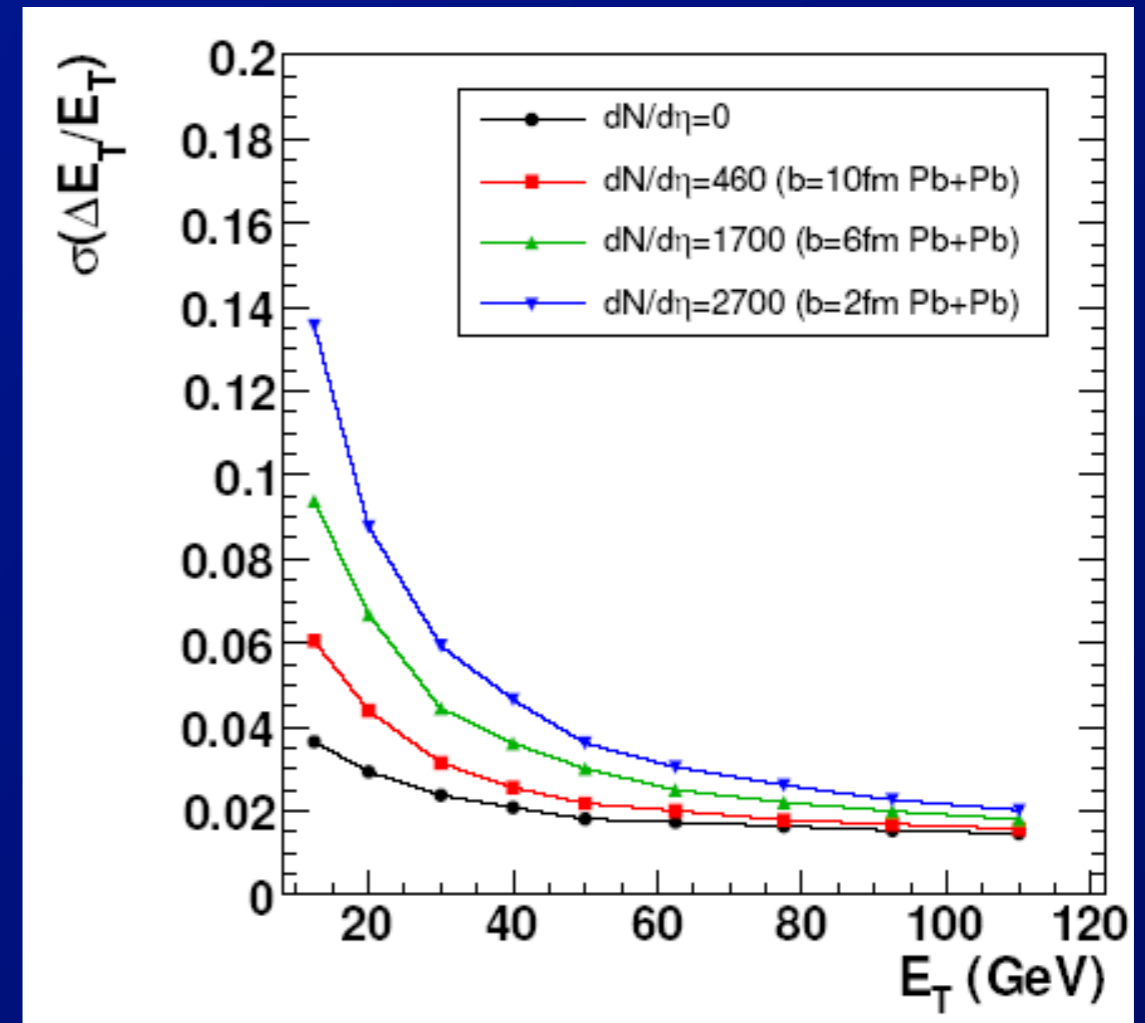
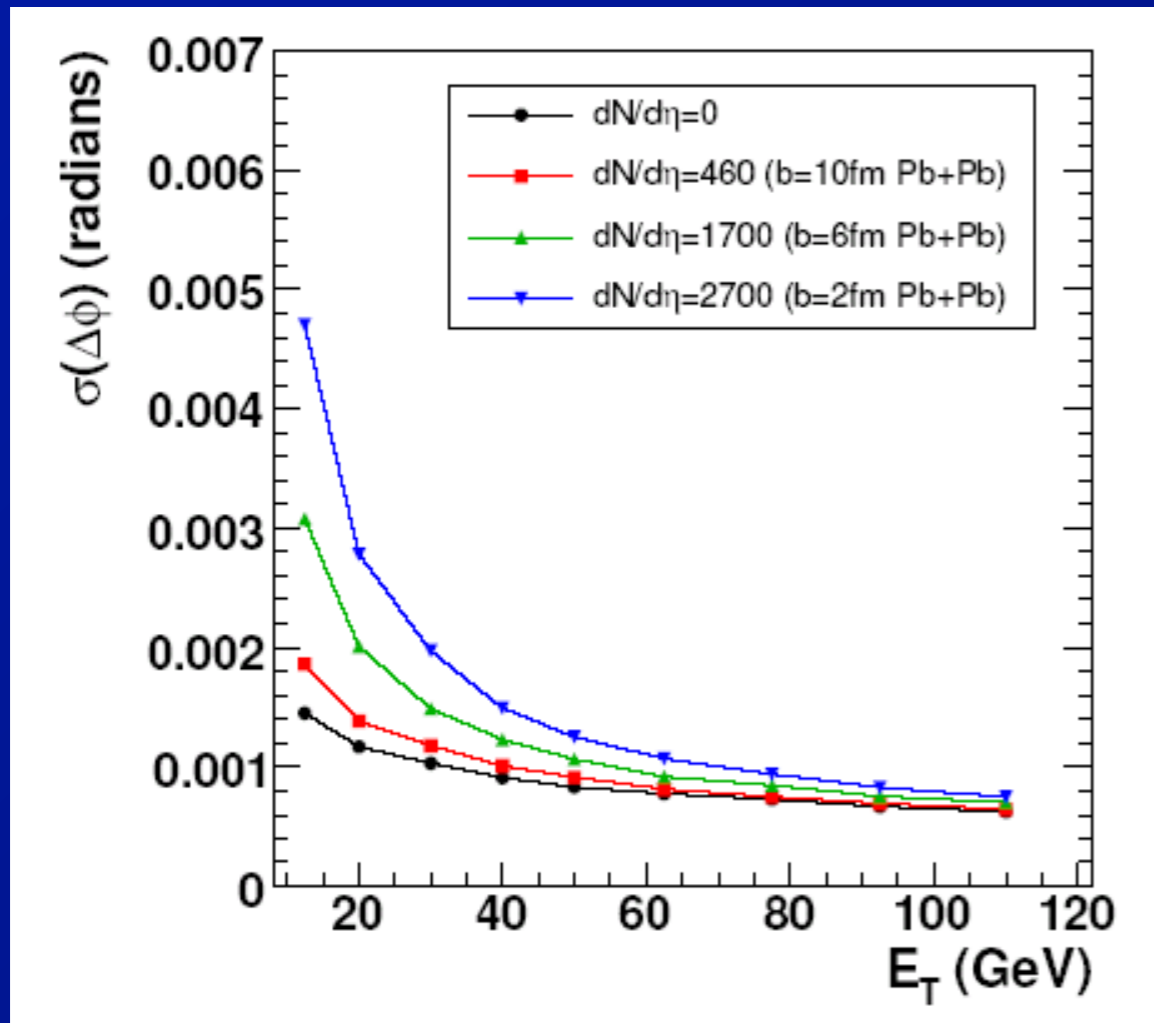
- Uniform tracking efficiency vs p_T , η
 - Crucial for controlling systematics on jet fragmentation measurements.
- Use matching to calorimeter to control fake rates at very high p_T .

ATLAS High p_T Spectrum Measurement



- No jet trigger or embedded jets
 - so statistics limited.
- But tracking performance uniform @ high p_T

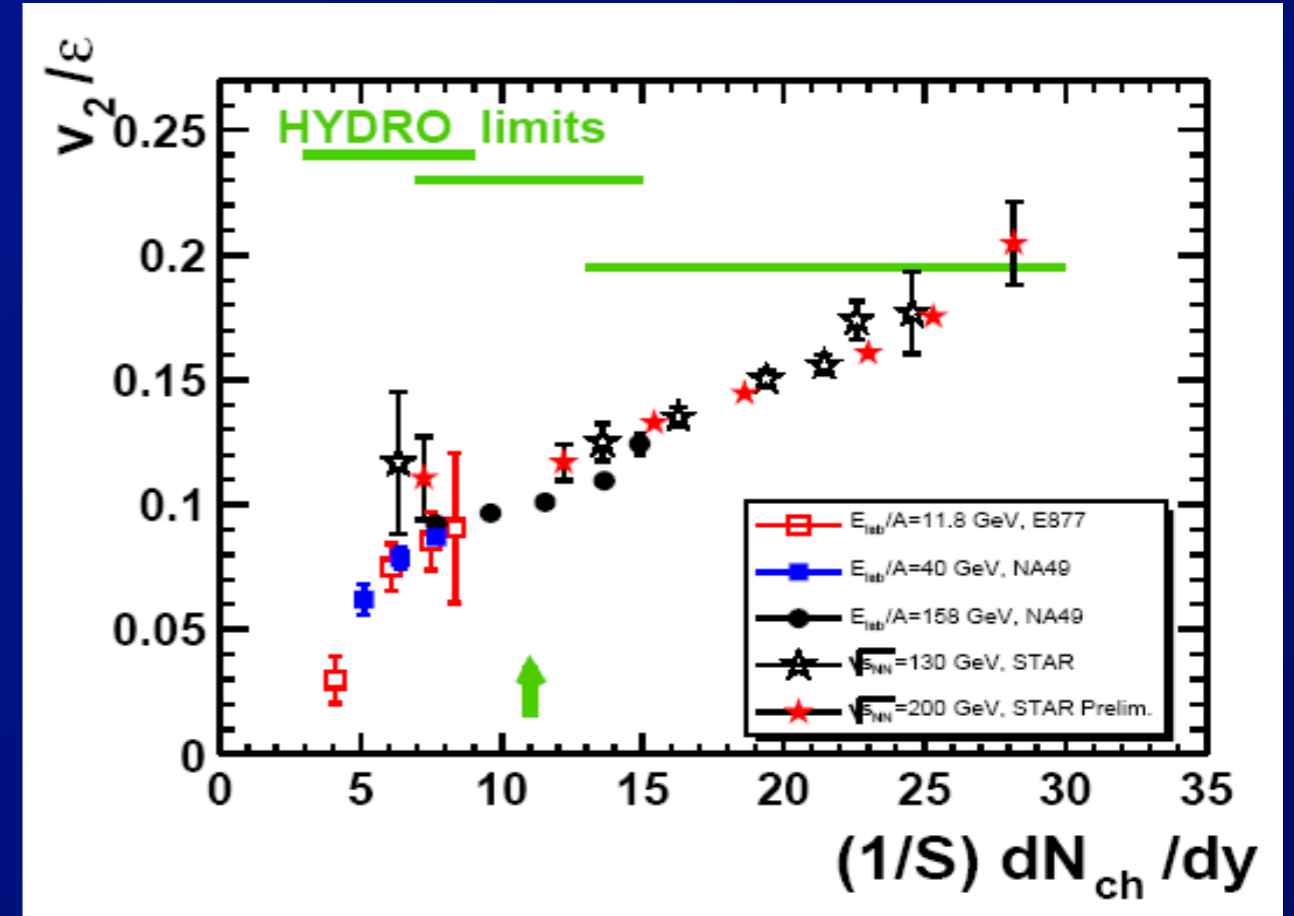
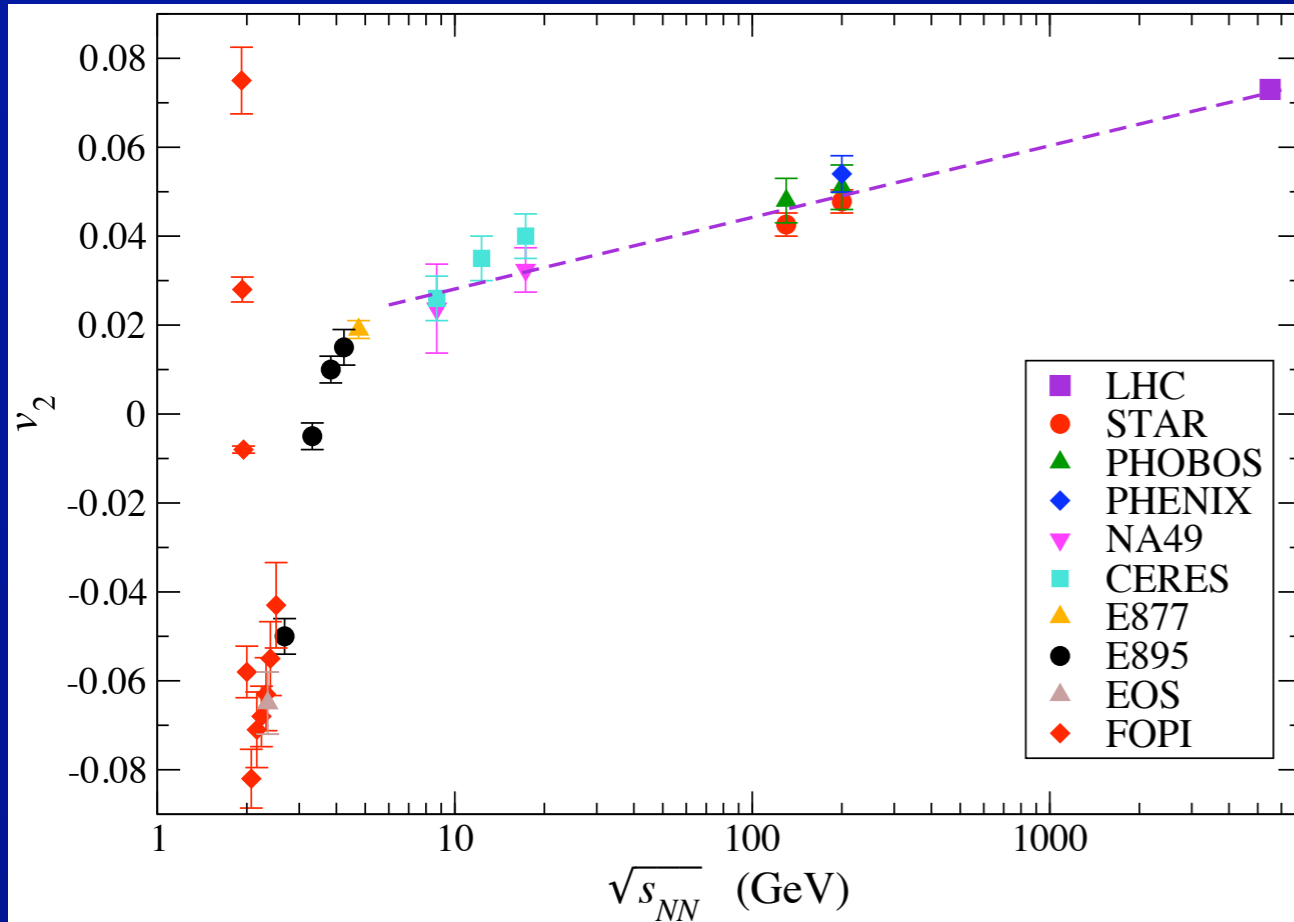
Photon Energy, Angular Resolution



- Photon measurement uses p-p algorithm
 - For now, only final correction for energy shift due to underlying Pb+Pb event.
 - ⇒ Layer-by-layer subtraction may be implemented.
 - Good energy, position resolution above 30 GeV.

Elliptic Flow, sQGP?

Wiedemann & Borghini, arXiv:0707.0564



• Will v_2 continue to increase from RHIC \rightarrow LHC?

– If so, why?

\Rightarrow Persistence of strong coupling at higher T ?

\Rightarrow Initial conditions (e.g. CGC eccentricity)?

\Rightarrow Reduced hadronic dissipation for $|\eta| \neq 0$?

ATLAS L1 Calorimeter ROIs in Pb+Pb

